Brain Science for Educators and Parents

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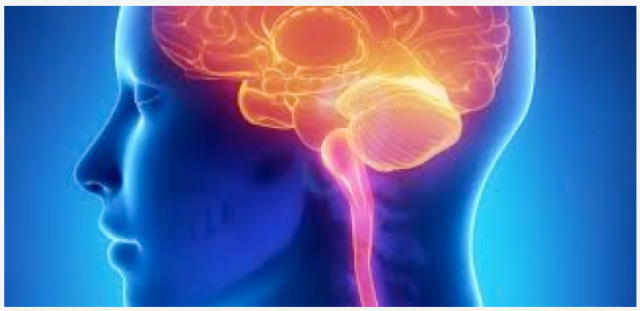

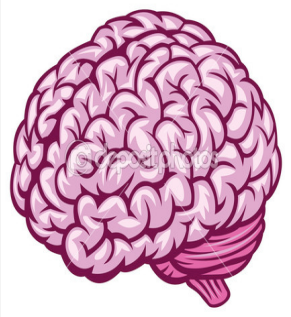

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Author

David Moursund is an Emeritus Professor of Education at the University of Oregon. During his teaching career he taught at the University of Wisconsin (Madison), Michigan State University, and the University of Oregon. While at the University of Oregon, he taught in the Mathematics Department, was the first head of the Computer Science Department, and spent many years teaching in the College of Education.

Moursund established the world's first doctoral program in Computers in Education. He was major professor or co-major professor of 82 doctoral students—six in Mathematics and 76 in Education.

Moursund's professional career includes founding the International Society for Technology in Education (ISTE) in 1979, serving as ISTE's executive officer for 19 years, and establishing ISTE's flagship publication, *Learning and Leading with Technology*. He has presented hundreds of professional talks and workshops. He has authored or coauthored more than 60 academic books and hundreds of articles. Many of these books are available free online. See http://iaepedia.org/David_Moursund_Books.

In 2007, after retiring from the University of Oregon, Moursund founded Information Age Education (IAE). The IAE website provides free online educational materials via its *IAE-pedia*, *IAE Newsletter*, *IAE Blog*, and books. Click here for details.

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Table of Contents

Preface

"Biology gives you a brain. Life turns it into a mind." (Jeffrey Eugenides; American Pulitzer Prize-winning novelist; 1960-.)

Publication History

The initial Brain Science entry in the *IAE-pedia* was published 12/19/2007, when the *IAE-pedia* was just getting started. Its content grew in a haphazard manner over the years. When I encountered a brain science article or topic that seemed particularly relevant to my interests—and to educators and parents—in education, I added it to the *IAE-pedia* Brain Science page. I made little effort to relate the new section to previous sections. Moreover, the topics were arranged in alphabetical order rather than being grouped into related topics.

In spite of these shortcomings, the Brain Science page grew in popularity. By the end of March, 2015, it had had about 107,000 page views—which made it fourth in popularity in the list of *IAE-pedia* content pages.

In April, 2015, I decided to reorganize and rewrite the *IAE-pedia* Brain Science document. Now, nearly four months later, I have completed this project. The result is this book, ***Brain Science for Educators and Parents.*** The book contains a great deal of information that I feel will prove valuable to educators, parents, and others who are interested in the capabilities and limitations of the human brain.

Overview

This introduction to brain science is specifically designed for preservice and inservice K-12 teachers, for teachers of these teachers, and for parents. Here are two important and unifying questions addressed throughout the book:

1. What should preservice teachers, inservice K-12 teachers, and parents know about brain science?
2. How should K-12 teachers be using their knowledge of brain science, both to improve their teaching and to help their students gain brain science knowledge appropriate to their current and growing cognitive development level?

The goal of the book is to help you develop and understand answers that fit your needs as an educator. If you have not read much about recent progress in brain science—and especially its applications in education—you might want to investigate some the documents and videos listed in the **References and Resources** section at the end of Chapter 1.

Each chapter focuses on a specific area of brain science in education. The grouping of topics into chapters—and indeed, the order of the chapters—is somewhat arbitrary. My suggestion is that you browse the Table of Contents and feel free to go directly to a topic that interests you. For example, dyslexia is one of a number of brain "disorders" discussed in Chapter 8. If you are specifically interested in dyslexia, you will find that the treatment of this topic in Chapter 8 is relatively independent of the content of the preceding chapters.

Each chapter is relatively self-contained, and ends with a section on **References and Resources** related to that chapter. While most of the items in References and Resources are specifically cited within the chapter, occasionally one will fall into the category of "additional suggested resources." Most entries are followed by a brief statement designed to help the reader link the reference content to the chapter content. The book ends with a final section on Videos for *Brain Science for Educators and Parents.* This lists all of the videos referenced in the book, organized by the chapter in which they appeared.

Getting Started

When I study a subject that is somewhat unfamiliar to me, I like to look at some of the older literature in the field. What were the frontiers of the field a decade or two ago? I find that I can understand the "leading edge" overview presentations from that time period.

Michael Merzenich is a world-class researcher and developer in educational applications of brain science. His 2004 *TED Talks*, Growing Evidence of Brain Plasticity, is now more than ten years old (Merzenich, 2004). I strongly recommend that you view this video before proceeding further in this book.

A Brief and Enjoyable Interlude

Before you get involved in the deep aspects of brain science and its applications to teaching and learning, I want you to enjoy a classic, short video about teaching tennis (Gallwey, 1970). It illustrates a type of coaching (a type of teaching) that has mind and body learning together in a non-threatening, natural, enjoyable, learn-by-doing, mind/body style.

References and Resources for Preface

Each chapter ends with a **References and Resources** section. The first two items listed below are cited in the Preface, and the remainder are not. The uncited materials provide background information that many readers will find interesting and useful.

GaIlwey, T.W. (1970). Inner game of tennis. (Video, 12:14.) Retrieved 6/21/2015 from https://www.youtube.com/watch?v=ieb1lmm9xHk. Quoting from the website:

> In 1970 W. Timothy Gallwey author of "Inner Game of Tennis," demonstrates how to teach tennis without teaching. A woman who doesn't know how to play tennis at all, can play within 10 minutes.

Merzenich, M. (2004). Growing evidence of brain plasticity. (Video, 23:07.) *TED Talks.* Retrieved 6/11/2015 from http://www.ted.com/talks/michael_merzenich_on_the_elastic_brain?language=en. Quoting from the website:

> Neuroscientist Michael Merzenich looks at one of the secrets of the brain's incredible power: its ability to actively re-wire itself. He's researching ways to harness the brain's plasticity to enhance our skills and recover lost function.

Schultz, L. (June, 2015). The surprisingly logical minds of babies. (Video, 20:18.) *TED Talks*. Retrieved 7/16/2015 from http://www.ted.com/talks/laura_schulz_the_surprisingly_logical_minds_of_babies/transcript?language=en.

An enlightening and amusing introduction to the amazing capabilities of the minds of babies. Laura Schultz argues that pre-toddlers and toddlers have mind capabilities that exceed the artificial intelligence of current computers—and the computers she expects to see for many years to come.

Sousa, D., ed. (2010). *Mind, brain, and education: Neuroscience implications for the classroom.* Bloomington, IN: Solution Tree.

The 17 contributors to this book have produced a "tour de force" that I consider must reading for anyone seriously interested in brain science in education. The book addresses questions such as "What does neuroscience reveal about the brain's ability to learn and use spoken language, to learn and use mathematics, and to think creatively?"

Sylwester, R. (2010). *A child's brain: The need for nurture.* Thousand Oaks, CA: Corwin. Quoting from the book:

> Although children often grouse about adult requests and decisions, they can't survive on their own and so are much more compliant then adolescents—who are reaching for autonomy.
>
> …
>
> Extended family, teachers, social workers, coaches, scouting leaders, religious guides, police, and others combine their efforts to help ensure that children are properly sheltered and nurtured.

Sylwester, R. (2007). *The adolescent brain: Reaching for autonomy*. Thousand Oaks, CA: Corwin. Quoting from the book:

> A variety of collaborative adult mentors accompany the adolescent reach for autonomy. Parents, stepparents, and other relatives form one group, and surrogate parents form the other group. Teachers, coaches, and youth program directors are examples of surrogate parents who work principally with groups of adolescents.

Chapter 1. Introduction to Brain Science

"I could while away the hours
Conferrin' with the flowers
Consultin' with the rain
And my head I'd be scratchin'
While my thoughts were busy hatchin'
If I only had a brain."

The scarecrow song in *Wizard of Oz*. (L. Frank Baum; American author; 1856-1919.)

Your 3-pound physical brain is part of your physical body. Quoting from the Wikipedia:

> The brain is an organ that serves as the center of the nervous system in all vertebrate and most invertebrate animals…. The brain is located in the head, usually close to the primary sensory organs for such senses as vision, hearing, balance, taste, and smell…. In a typical human, the cerebral cortex (the largest part [of the brain]) is estimated to contain 15–33 billion neurons, each connected by synapses to several thousand other neurons.

The typical human physical brain grows and matures over a period of years. Although it reaches 90% of its eventual full size by about age six, it doesn't reach full physical maturity until approximately age 26.

The non-brain parts of the physical body of a typical human grows and matures over a period of years, reaching full maturity by approximately ages 18 to 21.

Notice the difference between maturity of a physical body and maturity of a brain. Eighteen-year-old college freshmen may look mature, but their brains still have a long way to go!

Moreover, in terms of a brain, full physical maturity doesn't begin to tell the whole story. Your *brain* houses a *mind.* There is a considerable difference between the three-pound physical structure we call a *brain,* and the consciousness, education, training, and memories that we call a *mind* stored in the brain.

Quoting from the Wikipedia:

> A *mind* is the set of cognitive faculties that enables consciousness, perception, thinking, judgment, and memory—a characteristic of humans, but which also may apply to other life forms.

What is consciousness?—a seemingly simple question—is an important and challenging question at the frontiers of brain science. A later section of this book presents some of the latest findings.

While some authors strive to differentiate between brain and mind, others just use brain/mind to encompass the combination. This book tries to avoid getting bogged down in brain versus mind—sometimes using the term *brain/mind,* sometimes using just *brain* (especially when talking about the physical structure), and sometimes using just *mind* (especially when talking about thinking, consciousness, and attention).

When you go to sleep, the consciousness state of your brain/mind changes, but your brain/mind continues to function quite actively. You have a subconscious that can continue to work on a problem even when you are not actively paying attention to the problem and working to solve it. A person can wake from sleep and discover that an "ah ha" event or moment has occurred—the subconscious has made progress in solving a challenging problem.

And, you may have heard of the locked in syndrome, in which a patient may be completely paralyzed but still have a functioning brain/mind—and be completely unable to communicate. Recent progress in using sophisticated equipment to read brain waves is helping to develop ways to communicate with people who are completely locked in.

Through appropriate exercise and training, your physical body can gain in capabilities for a great many years after it reaches physical maturity. Similarly, through informal and formal education and experiences, your brain/mind continues its growth, development, and change throughout your lifetime.

You realize, of course, that physical and mental health and development are closely linked. A brain/mind needs a healthy physical body, and a physical body needs a healthy brain/mind. Thus, for example, if we reduce or delete daily physical education from a student's life, we are potentially damaging students' brain/minds. This issue is addressed in later parts of the book.

Elkhonon Goldberg is a world leader in brain science. Quoting from Andy Hunter's interview, On The Threshold: An Interview With Elkhonon Goldberg, Ph.D. (Hunter, 3/31/2011):

> Elkhonon Goldberg is one of those rare scientists who are able to distill complex ideas into accessible, entertaining, and even literary prose. His books The Wisdom Paradox and The Executive Brain are as compulsively readable as they are insightful and instructive.
>
> **Question: What do you think is the single most important thing that a person should understand about his or her brain?**
>
> How about if I tell you two things? One very important thing that one should understand is that one's brain is part of one's physical body. When we think about our ability to breathe, digest, or walk, we understand that these are all functions of our bodies. But when people think about our ability to think, have emotions, or make decisions, they often think as if these were some kind of platonic, ex-corporeal phenomenon, which have nothing to do with our physical being. In reality, they're functions of our brain, and the brain is a biological entity which is part of our body.
>
> The other thing that's important is that we are in command of what happens to our brain. Like other organs in our bodies, our brain is very malleable, and depending on what we do—or fail to do—with it, it will be healthy and function well, or it will succumb to the effects of aging or other infirmity and it will not function well. Most people understand that we can go to the gym to change the structure of your body. But relatively few people understand in a deep sense that our mind can also be molded through the nature of our mental activity.
>
> **Question: Does that include things like how you eat, or your physical condition, as well as whatever mental exercise you do during the day?**

> All of the above. Obviously, since thinking is a function of the brain, the most direct impact on the brain is through mental activities. One should not shy away from situations where you strain your brain; one should always be mentally active and engage in new challenges. The rigor of your mental activity has a direct effect on the brain, but so does the nature and extent of your physical activities. It has been shown that a physical, active lifestyle promotes various physiological phenomena that are good for your brain. Nobody's life should gravitate to excesses. It should be a balanced menu of physical and mental activities.

History of Brain Study

Intelligence is the ability to acquire and make use of knowledge and skills—it is the ability to adapt to change. This is a very broad and inclusive definition. All living creatures have intelligence, and humans have a very long history of being interested in intelligence.

However, a "science" of studying the brain and mind was slow to develop. For example, during the 1800s, phrenology was considered by many to be an important approach to studying the brain. Quoting from the phrenology website:

> …so it was believed that by examining the shape and unevenness of a head or skull, one could discover the development of the particular cerebral "organs" responsible for different intellectual aptitudes and character traits. For example, a prominent protuberance in the forehead at the position attributed to the organ of Benevolence was meant to indicate that the individual had a "well developed" organ of Benevolence and would therefore be expected to exhibit benevolent behavior.

Brain science took a major leap forward through the work of Alfred Binet and others in developing the concept of IQ in the early 1900s. Quoting from the linked website:

> Intelligence testing began in earnest in France, when in 1904 psychologist Alfred Binet was commissioned by the French government to find a method to differentiate between children who were intellectually normal and those who were inferior. The purpose was to put the latter into special schools where they would receive more individual attention. In this way, the disruption they caused in the education of intellectually normal children could be avoided.

This led to the development of the Binet Scale, also known as the Simon-Binet Scale in recognition of Theophile Simon's assistance in its development. The IQ is the ratio of "mental age" to chronological age, with 100 being average. An 8-year-old who passes the 10-year-old's test would have an IQ of 10/8 x 100, or 125.

Now, more than a century later, various theories of IQ and measures of IQ are still active areas of study and research. A theory of multiple intelligences (a person having more than one type of cognitive intelligence) has been put forth by Howard Gardner, Robert Sternberg, and others. Other types of intelligence, such as social and emotional intelligence, are also being studied.

Brain Science

The field of brain science (also called cognitive neuroscience) is expanding quite rapidly. It may well be that the totality of knowledge in this area is doubling every five years. You can get a sense for the breadth and depth of research going on in this field by viewing a 5:37 video from

the Allan Institute for Brain Science (Allan Institute, 2015). For much greater breadth and depth, see the free University of Texas online textbook, *Neuroscience Online* (University of Texas, 1997-present).

It is only in recent years that technology and brain theory have progressed to a stage that allows us to gain an understanding of how brains work at the neuron level. Non-invasive brain scanning neuroimaging equipment has come onto the scene and has added very important new dimensions to the field of brain science. Quoting from the Wikipedia:

> Neuroimaging falls into two broad categories:
>
> - Structural imaging, which deals with the structure of the brain and the diagnosis of gross (large scale) intracranial disease (such as tumor), and injury, and
> - Functional imaging, which is used to diagnose metabolic diseases and lesions on a finer scale (such as Alzheimer's disease) and also for neurological and cognitive psychology research and building brain-computer interfaces.

In addition, our increased understanding of genes is providing information about a variety of brain "defects" and diseases. We are developing useful interventions based on brain education (training, retraining) and drugs.

Our increased understanding of brain functioning is quite important in education. A superb example is provided by the research and development in *dyslexia,* a relatively common reading disorder. Appropriate interventions can actually "rewire" the brain and help many dyslexics to become good readers. This topic is discussed later in this document.

A Good Source of Educational Materials

There are a number good sources of brain science and education materials. Many of them are woven into the subsequent chapters of this book. However, here is one you might want to explore right now.

The DANA Foundation's website http://www.dana.org/educators/ provides substantial amounts of educational material. For example, here you can access:

- **BioEd Online: Biology Teacher Resources.** Baylor College of Medicine has resources for K-8 and high school biology teachers, including lesson plans, news stories, and classroom activities.
- **The Brain From Top to Bottom.** This site, from the Canadian Institutes of Health Research's Institute of Neurosciences, Mental Health and Addiction sponsors, offers in-depth information to students of all levels about such brain-related issues as the senses, memory, pleasure and pain, and mental disorders.
- **The ChemCollective.** The ChemCollective offers teachers and students free virtual lab materials, tutorials, scenarios, and simulations to use in class, along with an opportunity for teachers to share materials with one another. The National Science Digital Library and the National Science Foundation sponsor the site.

The Dana Alliance for Brain Initiatives was officially launched in 1993. Its founding members pledged their commitment to advancing public awareness and education about the progress and promise of brain research, and to disseminating information on the brain in an understandable and accessible manner. See more at:
http://www.dana.org/About/DABI/#sthash.m3fIsKlc.dpuf.

Consciousness and Self-awareness

> "Cogito ergo sum. I think, therefore I am." (René Descartes; French philosopher, mathematician, scientist, and writer; 1596-1650.)

Not only do you and other humans think, you can think about the past and plan for the future. (You are saving for your eventual retirement, right?) Consciousness has long been a far frontier of the field of brain science. In recent years, significant progress is occurring in understanding this phenomenon, but we have a long way to go.

What might it mean to say that we understand what consciousness is and what makes/creates consciousness? Quoting from Steven Pinker, The Mystery of Consciousness (Pinker, 1/29/2007):

> It shouldn't be surprising that research on consciousness is alternately exhilarating and disturbing. No other topic is like it. As René Descartes noted, our own consciousness is the most indubitable thing there is. The major religions locate it in a soul that survives the body's death to receive its just deserts or to meld into a global mind. For each of us, consciousness is life itself, the reason Woody Allen said, "I don't want to achieve immortality through my work. I want to achieve it by not dying." And the conviction that other people can suffer and flourish as each of us does is the essence of empathy and the foundation of morality.
>
> ...
>
> Another startling conclusion from the science of consciousness is that the intuitive feeling we have that there's an executive "I" that sits in a control room of our brain, scanning the screens of the senses and pushing the buttons of the muscles, is an illusion. Consciousness turns out to consist of a maelstrom of events distributed across the brain. These events compete for attention, and as one process outshouts the others, the brain rationalizes the outcome after the fact and concocts the impression that a single self was in charge all along.

Both the United States and the European Union are embarking on large, long-term brain projects. Shortly before the New Scientist Consciousness and the Extended Mind event held in England (4/7/2015), Liz Else interviewed Margaret Boden, one of the participants (Else, 3/31/2015). Quoting from the article:

> **Big money is being spent on initiatives like the European Union's Human Brain Project. Will people hoping to learn about consciousness be disappointed?**
>
> Absolutely. From what I hear, some of that project's neuroscientists are disappointed because it isn't nearly strong enough in asking cognitive questions. It is asking the basic, materialistic questions—such as which cells connect with what, or which chemicals are diffusing—but these basic questions aren't the only important ones.
>
> **So are we much closer to grasping consciousness than when you started work on it, four decades ago?**
>
> Not very. I think the fundamental problems aren't just scientific—knowing what's going on in the brain when we're conscious and so forth—but philosophical questions, and in particular about the phenomenon of consciousness. This concerns the so-called hard problem of how conscious experience emerges from matter, and why we experience, say,

> the redness of red or feel pain. It isn't just that we're not sure what scientific questions to ask; it's that we don't know what questions to ask because we don't know what we're talking about.
>
> **So where have we seen progress?**
>
> One area is in understanding functional consciousness, such as decision-making. And we understand more about how systems in the brain cooperate and integrate to make conscious or unconscious decisions.

Mythologies About the Human Brain

> "The great enemy of the truth is very often not the lie — deliberate, contrived, and dishonest — but the myth — persistent, persuasive, and unrealistic." (John F. Kennedy; 35th president of the United States; 1917-1963.)

We each have some knowledge about our own brains and the brains of other people. Some of your knowledge may fall into the category of "mythologies." A 4/29/2015 Google search of the expression *brain myths in education* produced over 15 million results.

Quoting from Pete Etchells' article, Brain Baloney Has No Place in the Classroom (Etchells, 10/17/2014):

> If you want to make a neuroscientist's head explode, all you need to do is confidently and triumphantly tell them that humans only use 10% of their brains. Or that right-brained people are more creative than left-brained people. Or that jiggling your head around gets more blood to the brain so you can think more efficiently. These are myths about the brain that have now been around for so long, it's a wonder they haven't had a congratulatory message from the Queen.

The field of brain science is making amazing progress. Many people read a little bit about this progress and try to translate it into ways to solve problems or accomplish tasks in their own particular areas of interest. In the process they may create neuromythologies that others come to believe are true and accept without question.

In education, we now have a great many neuromythologies. You might ask yourself, what does a person gain by believing a myth even when there is substantial research evidence that says the myth is incorrect? Doing so makes you a less credible person and belittles the discipline you are talking about. IAE has published a collection IAE Newsletters on the topic of credibility and validity.

For example, consider the 10% brain use mythology mentioned above. Such a myth is often accompanied by various techniques (more studying, meditation, drugs) suggesting that one can learn to make use of a much greater part of their brain.

Now that we have appropriate brain-scanning equipment, we know for a fact that 10% is a ridiculously low estimate. Even in mundane tasks, nearly 100% of our brain neurons are engaged.

Learning styles is another popular area of mythology. We all have heard about VAK (visual, auditory, and kinesthetic) learners. It seems obvious that a person might be a lot better in one of

these learning modalities than in the other two. From this one might conclude that education can be improved by teaching students almost completely in their best learning modality.

This is incorrect. What's the Story on Learning Styles? by Maryellen Weimer provides a nice summary of this topic (Weimer, 4/30/2014). Quoting from her article:

> Then several years ago, we started seeing articles that challenged the validity of learning styles (see Pashler, et al. for an example). The Pashler et. al literature review did not find empirically valid evidence connecting learning styles with instructional methods and better learning outcomes for students with that style when compared to students with other styles. And so, challenged empirically and questioned in several widely referenced articles, **learning styles are now out**. [Bold added for emphasis.]
>
> However, what's left standing is one unarguable fact: People do not all learn in the same way. Some of us always read the instructions first and others of us just start putting it together.

John Geake's Neuromythologies in Education is an excellent research-based article on the fallacy of believing in neuromythologies (Geake, 2008). His article discusses the 10% myth, the learning styles myth, the left- and right-brained thinking myth, and a number of others.

Mind, Brain, and Education: Neuroscience Implications for the Classroom (Sousa, 2010) provides a number of examples of neuromythologies and an excellent introduction to mind, brain, and education.

You and Your Students

> "No two minds ever come together without thereby creating a third, invisible, intangible force, which may be likened to a third mind." (Napoleon Hill; American author; 1883-1970.)

As you read this book, think about possible applications in your own professional and personal life, and think about what you want students to know about the various topics. The brain myths mentioned in this chapter provide an interesting challenge. Perhaps you strongly disagree with the research on brain myths. What are you going to do about this situation?

You may enjoy working with your students to find out what they "know" (think they know) about their own brains. Here are some possible topics for small group and whole class discussion, or writing assignments.

- Do your students believe that girls are naturally smarter than boys, or vice versa?
- Do they believe that left-handers are smarter than right-handers, or vice versa?
- What do they "know" about multitasking?
- What do they "know" about study skills—how one learns new material? Do they use different approaches to learning different subject areas?
- To them, what does it mean "to know and understand" something? How do students know that they know something? For example, how does one know they have learned the math they are studying versus the history they are studying? How do they self-assess?

These and similar questions can spark interesting class discussions and student research projects.

References and Resources for Chapter 1

Allan Institute (2015). Allan Institute for Brain Science: Fueling discovery. (Video, 5:37.) Retrieved 4/27/2015 from http://alleninstitute.org/news-events/videos/.

The non-profit Allan Institute was founded by Paul Allan, one of the founders of Microsoft. The Institute carries out research on fundamental, challenging brain science topics, and shares its results with researchers throughout the world.

Brandt, R. (April, 2012). How educational neuroscience will contribute to 21st century education. *IAE Newsletter.* Retrieved 4/23/2015 from http://i-a-e.org/newsletters/IAE-Newsletter-2012-87.html.

Ron Brandt was editor of publications for the Association for Supervision and Curriculum Development (now ASCD), from 1978 until his retirement in 1997. This newsletter summarizes some of the early history of bringing "modern" brain science into education.

Else, L. (3/31/2015). We must pull together to grasp consciousness. *New Scientist*. Retrieved 5/31/2015 from http://www.newscientist.com/article/dn27272-we-must-pull-together-to-grasp-consciousness.html?utm_source=NSNS&utm_medium=SOC&utm_campaign=hoot&cmpid=SOC%257CNSNS%257C2014-GLOBAL-hoot#.VU0CH2BBIf9. Quoting from the article:

> Are robots with human-like intelligence just around the corner? Are we close to understanding consciousness?

Etchells, P. (10/17/2014). Brain baloney has no place in the classroom. *theguardian.* Retrieved 6/19/2014 from http://www.theguardian.com/science/head-quarters/2014/oct/17/brain-baloney-neuro-myths-teaching-education-classroom?CMP=share_btn_tw. Quoting from the article:

> And so we're left with a situation in which neuromyths have largely been left unchallenged in the education system. But, at least there's a spark of hope that this is changing. Both teachers and neuroscientists alike are starting to see an increased need for better communication.

Geake, J. (2008). Neuromythologies in education. *Educational Research*. Retrieved 10/4/2013 from http://amyalexander.wiki.westga.edu/file/view/neuromythologies-p.pdf. Quoting from the article:

> The basis for the argument put forward includes a literature review of relevant cognitive neuroscientific studies, often involving neuroimaging, together with several comprehensive education reviews of the brain-based approaches under scrutiny.

Howard-Jones, P. (10/15/2014). Neuroscience and education: Myths and messages. *Nature*. An abstract of this research article is available at http://www.nature.com/nrn/journal/v15/n12/full/nrn3817.html.

A newspaper article based on the research is available at http://www.theguardian.com/science/head-quarters/2014/oct/17/brain-baloney-neuro-myths-teaching-education-classroom.

Hunter, A. (3/31/2011). On the threshold: An interview with Elkhonon Goldberg, Ph.D, *BrainWorld.* Retrieved 7/5/2015 from http://brainworldmagazine.com/on-the-threshold-an-interview-with-elkhonon-goldberg-ph-d/. Quoting from the article:

> …neuroscience has finally crossed the threshold of being a real science. Thirty or 40 years ago, it was in a prescientific, intuitive state. People had certain ideas and concepts, but there was no rigorous body of methods or knowledge to justify calling it a real science. Now, finally, neuroscience is coming of age into a serious, rigorous science.

Kanwisher, N. (2014). Nancy's brain talks. (Videos, various lengths.) Retrieved 4/23/2015 from http://nancysbraintalks.mit.edu. Quoting from the website:

> Welcome! I'm a professor at MIT who uses a brain imaging method called fMRI to study the human brain. This site contains short talks on the different scientific methods we can use to study the human mind and brain, and some of the cool things we have learned so far. You do not need any background in the field to understand the talks. For an overall introduction, watch my [March, 2014] *TED Talks*.

Pinker, S. (1/19/2007). The mystery of consciousness. Retrieved 5/31/2015 from http://www.time.com/time/magazine/article/0,9171,1580394,00.html. Quoting from the article:

> The Easy Problem, then, is to distinguish conscious from unconscious mental computation, identify its correlates in the brain and explain why it evolved.
>
> The Hard Problem, on the other hand, is why it feels like something to have a conscious process going on in one's head—why there is first-person, subjective experience.

Sousa, D., ed. (2010). *Mind, brain, and education: Neuroscience implications for the classroom.* Bloomington, IN: Solution Tree.

> The 17 contributors to this book have produced a "tour de force" that I consider must reading for anyone seriously interested in brain science in education. The book addresses questions such as "What does neuroscience reveal about the brain's ability to learn and use spoken language, to learn and use mathematics, and to think creatively?"

Sparks, S.D. (6/4/2012). Experts call for teaching educators brain science. *Education Week.* Retrieved 6/14/2012 from http://www.edweek.org/ew/articles/2012/06/06/33teachers.h31.html?tkn=QMCFdkGZMV2m7+qxClqvXh1WsWnWtdl0kNfT&cmp=clp-sb-ascd. Quoting from the article:

> "For the most part, teachers are not exposed systemically in a way that allows them to understand things like brain plasticity," said Michael J. Nakkula, the chairman of applied psychology and human development at the University of Pennsylvania's Graduate School of Education. Mr. Nakkula is part of the Students at the Center project, a series of reports on teaching and learning launched this spring by the Boston-based nonprofit group Jobs for the Future.

Sylwester, R. (August, 2013). Understanding and mastering complexity: Understanding our brain and applying that knowledge. *IAE Newsletter.* Retrieved 4/23/2015 from http://i-a-e.org/newsletters/IAE-Newsletter-2013-120.html. Quoting from the newsletter:

> The recent development of at least eight kinds of brain imaging technologies that measure and display variations in chemical composition, blood flow patterns, and electromagnetic fields opened up the possibility of studying brain organization and function in ways that were not previously thought possible.

University of Texas (1997-present). *Neuroscience online.* Department of Neurobiology and Anatomy at The University of Texas Medical School at Houston. Retrieved 5/3/2015 from http://neuroscience.uth.tmc.edu/index.htm.

Chapter 7 of Section 4 is titled, Learning and Memory. Quoting from this chapter:

> The analysis of the anatomical and physical bases of learning and memory is one of the great successes of modern neuroscience. Thirty years ago little was known about how memory works, but now we know a great deal.

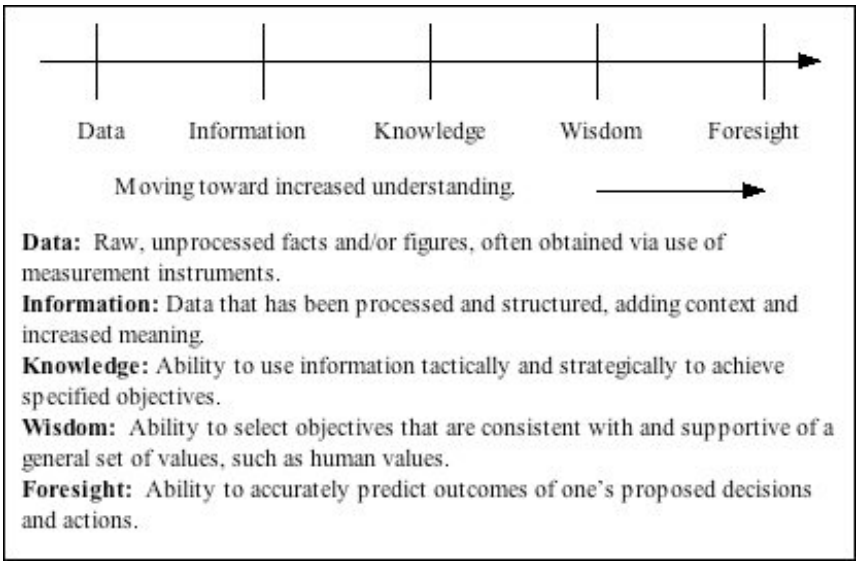
Weimer, M. (4/30/2014). What's the story on learning styles? *Faculty Focus*. Retrieved 5/30/2015 from http://www.facultyfocus.com/articles/learning-styles/whats-story-learning-styles/. Quoting from the article:

> [Over simplification of learning and learning styles] derives from dualistic thinking. Either something is right or wrong, it's in or out, up or down. As mature thinkers, we disavow these dichotomous perspectives.

Chapter 2. Executive Functions and Memory

> "The strongest memory is not as strong as the weakest ink." (Confucius; Chinese thinker and social philosopher, whose teachings and philosophy have deeply influenced Chinese, Korean, Japanese, Taiwanese and Vietnamese thought and life; 551 BC–479 BC.)

In this book, the term *information* is used to represent any combination of data, information, knowledge, wisdom, and foresight.



Frequently in my early teaching career, I taught a computer literacy course. In this course I taught my student that a computer is a machine for the input, storage, processing, and output of information. That is, a computer is a brain-like, information-processing machine. In my teaching, I emphasized that if we leave out the word *machine*, this description fits a human brain.

So, then as now, it is interesting and fun to involve students in discussing capabilities and limitations of the human brain versus those of a computer as a brain-like machine. Research and development in improving a computer's brain-like capabilities has both helped the field of brain science and has been helped by continued progress in brain science.

This chapter focuses on three important aspects of the human brain: executive function, attention, and memory. The executive parts of the brain are in charge, telling other parts what to do. A useful analogy is to think about how a company's Chief Executive Officer is in charge of the company.

The attention components direct the mind and senses to pay attention, and the memory stores information that can be used by the other parts of the brain to solve problems and accomplish tasks.

A University of Texas online book, *Welcome to Neuroscience Online, the Open Access Textbook,* is available free. Chapter 7 of Section 4 is titled, Learning and Memory.

Executive Functions of the Brain

The executive functions of a human brain are a set of processes that all have to do with managing oneself and one's resources in order to achieve a goal. It is an umbrella term for the neurologically-based skills involving mental control and self-regulation. Quoting from the Executive Functions section of (UCSF, n.d.):

> The term "Executive Functions" refers to the higher-level cognitive skills you use to control and coordinate your other cognitive abilities and behaviors. The term is a business metaphor, where the chief executive monitors all of the different departments so that the company can move forward as efficiently and effectively as possible. Who we are, how we organize our lives, how we plan, and how we then execute those plans is largely guided by our executive system.
>
> Executive functions can be divided into organizational and regulatory abilities. Organization includes gathering information and structuring it for evaluation. Regulation involves evaluating the available information and modulating your responses to the environment.

Here is a list of some functions quoted from *What Is Executive Functioning?* by Joyce Cooper-Kahn and Laurie Diet (2008):

- **Inhibition.** The ability to stop one's own behavior at the appropriate time, including stopping actions and thoughts. The flip side of inhibition is impulsivity; if you have weak ability to stop yourself from acting on your impulses, then you are "impulsive."
- **Shift.** The ability to move freely from one situation to another and to think flexibly in order to respond appropriately to the situation.
- **Emotional Control**. The ability to modulate emotional responses by bringing rational thought to bear on feelings.
- **Initiation**. The ability to begin a task or activity and to independently generate ideas, responses, or problem-solving strategies.
- **Working Memory**. The capacity to hold information in mind for the purpose of completing a task.
- **Planning/Organization**. The ability to manage current and future- oriented task demands.
- **Organization of Materials**. The ability to impose order on work, play, and storage spaces.
- **Self-Monitoring**. The ability to monitor one's own performance and to measure it against some standard of what is needed or expected.

Attention

You have probably heard teachers say, "Now class, please pay attention." The teachers want the students to focus their attention on new information and ideas that are about to be presented.

The Merriam-Webster dictionary defines *attention* as "the act or power of carefully thinking about, listening to, or watching someone or something."

Attention is an important brain executive function. Quoting from the Wikipedia:

> Attention is one of the most intensely studied topics within psychology and cognitive neuroscience. Attention remains a major area of investigation within education, psychology and neuroscience.

A longitudinal study and other research projects are reported in Katrina Schwartz's article, Age of Distraction: Why It's Crucial for Students to Learn to Focus (Schwartz, 12/5/2013). Quoting from the article:

> Perhaps the most well-known study on concentration is a longitudinal study conducted with over 1,000 children in New Zealand by Terrie Moffitt and Avshalom Caspi, psychology and neuroscience professors at Duke University. The study tested children born in 1972 and 1973 regularly for eight years, measuring their ability to pay attention and to ignore distractions. Then, the researchers tracked those same children down at the age of 32 to see how well they fared in life. **The ability to concentrate was the strongest predictor of success.**
>
> **"This ability is more important than IQ or the socio economic status of the family you grew up** in for determining career success, financial success and health," Goleman said. [Bold added for emphasis.]

Michael Posner has long been a world leader in attention. In his video interview, Implications of Cognitive Neuroscience for Education, Posner describes research on attention and the executive function of the brain—especially as they apply to learning a natural language (Posner, 2009). This research provides us with increased understanding of the brain functioning of infants. It also helps to explain why both *phonetics* and *whole word* teaching are important in learning to become a fluent reader. One part of the brain deals with phonemes and a different part deals with whole words.

Posner's interview includes a brief discussion about research on infants' ability to distinguish between small numbers—perhaps up to four or five. Research on infants learning language and math provides solid evidence of the role of parents and other child care providers in very early childhood education.

Attention Deficit Hyperactivity Disorder (ADHD)—sometimes called Attention Deficit Disorder (ADD)—is a relatively prevalent learning disorder. Quoting from a Mayo Clinic website (Mayo Clinic Staff, 2015):

> Attention-deficit/hyperactivity disorder (ADHD) is a chronic condition that affects millions of children and often persists into adulthood. ADHD includes a combination of problems, such as difficulty sustaining attention, hyperactivity and impulsive behavior.
>
> Children with ADHD also may struggle with low self-esteem, troubled relationships and poor performance in school. Symptoms sometimes lessen with age. However, some people never completely outgrow their ADHD symptoms. **But they can learn strategies to be successful.** [Bold added for emphasis.]

The last sentence quoted above is particularly important. According to the U.S. Center for Disease Control (CDC, 2015) currently "treatment" for ADHD usually consists of a combination of:

- Medications
- Behavioral intervention strategies
- Parent training
- School accommodations and interventions

Chapter 8 contains an extensive section on ADHD.

Long-term Memory

Quoting from the Wikipedia:

> **Declarative memory** (sometimes referred to as explicit memory) is one of two types of long-term human memory. Declarative memory refers to memories that can be consciously recalled such as facts and knowledge. … Declarative memory's counterpart is known as non-declarative or procedural memory, which refers to unconscious memories such as skills (e.g. learning to ride a bicycle). Declarative memory can be divided into two categories: episodic memory, which stores specific personal experiences, and semantic memory, which stores factual information.

As indicated earlier in this chapter, we use the term *information* to represent any combination of data, information, knowledge, wisdom, and foresight. Information stored in a computer's memory is represented in binary code—as a sequence of zeros and ones. That is **not** how we store information in our brains!

One popular—but incorrect—mental image or analogy of human long-term memory is a collection of very tiny filing cabinets, perhaps with the information arranged in alphabetical order. The information just sits there, waiting to be retrieved.

This is an interesting analogy, but rather weak. For example, when you think about animals, do you direct your brain to look in the "A" part of its memory system? Certainly not. The content in your brain's memory is not arranged in alphabetical order.

Consider the complexity of a storage and retrieval system that can find/access appropriate information when it sees the word *animal* in print, hears the word, sees any of many different animals in the flesh or in pictures, hears the sound of an animal, smells an animal, is asked to describe some different four-footed animals, and so on.

Quoting from Luke Mastin's website, The Human Memory (Mastin, 2010):

> …our memory is located not in one particular place in the brain, but is instead a brain-wide process in which several different areas of the brain act in conjunction with one another (sometimes referred to as distributed processing). For example, the simple act of riding a bike is actively and seamlessly reconstructed by the brain from many different areas: the memory of how to operate the bike comes from one area, the memory of how to get from here to the end of the block comes from another, the memory of biking safety rules from another, and that nervous feeling when a car veers dangerously close comes from still another. Each element of a memory (sights, sounds, words, emotions) is encoded in the same part of the brain that originally created that fragment (visual cortex,

> motor cortex, language area, etc), and recall of a memory effectively reactivates the neural patterns generated during the original encoding.

This distributed-memory aspect of information stored in a human brain provides an important clue to effective learning to facilitate information retrieval. Each chunk of information that you store in your brain becomes distributed and connected to (associated with) many other different chunks of information. When we "understand" something, we have stored, can retrieve, and can make use of a collection of interrelated information.

So, in learning something new, we relate it to things we already know, understand, and can use. That, is constructivism is a natural process of how a human learns. As we try to remember (retrieve) information from our memory, we depend on our brain finding and assembling widely distributed but related pieces of memory elements. We improve our retrieval capabilities by helping our brains make a widely distributed but interrelated schema for whatever we are trying to learn.

This analysis also helps to explain why rote learning without understanding is not an effective process. Isolated pieces of information that may well be stored in one's brain are often difficult to retrieve.

Sensory Memory

Each of our five senses has some short-term memory. You have probably experienced this in your auditory sense. You are not paying much attention to what is being said, and somehow your subconscious says, "Pay attention to what you are hearing." Your short-term auditory memory allows you to retrieve (in essence, sort of rehear) the last few seconds of the auditory signal.

Quoting from the Wikipedia:

> Humans have five main senses: sight, hearing, taste, smell, touch. Sensory memory (SM) allows individuals to retain impressions of sensory information after the original stimulus has ceased.
>
> During every moment of an organism's life, sensory information is being taken in by sensory receptors and processed by the nervous system. The information people receive which is stored in sensory memory is just long enough to be transferred to short-term memory.

Sensory memory stores only a quite short length of input. Depending on the particular sense, this might be as little as a tenth of a second up to a perhaps two-three seconds (Ricker, n.d.). Information coming into sensory memories is transferred into the brain's short-term working memory (which is discussed later in this chapter). There, the brain processes the information.

In a conversation, for example, the incoming information is often combined with information stored in long-term memory to produce a verbal response. Think about the complexities of receiving a signal consisting of vibrations in the air, translating that into information stored in short term (working) memory, understanding what the signal means, retrieving additional information from one's long-term memory that relates to what has been said, formulating a response, and directing one's speaking mechanism to utter a response.

Most of the sensory information that we take in is ignored—that is, does not come to the attention of short-term memory. This observation reinforces our understanding of attention. If we don't pay attention to sensory inputs, we do not learn from them.

Short-term Memory (Working Memory)

Short-term memory has come to be called *working memory,* and in the remainder of this chapter we will use that term. If a person tells you their 10-digit phone number, can you remember it long enough to write it down? If you can remember a random 10-digit sequence of number long enough to write them down, your working memory is quite unusual.

But, suppose that you know the person has a local phone number, and you live in the same area code. Then the person's phone number consists of "my area code" followed by a seven-digit number. The 10-digit number has been reduced to eight chunks of information. Eight chunks are easier to remember for the short time it takes to write it down or "dial" it.

George Miller's 1956 research article, The Magical Number Seven Plus or Minus Two: Some Limits on Our Capacity for Processing Information, is a classic and well worth reading (Miller, 1956). It discusses the capabilities and limitations of working memory, and argues that for typical people, working memory is approximately five to nine chunks.

The size (capacity) of memory varies significantly with different people, and it also varies under conditions of stress, drugs, and so on. Quoting from Miller's article:

> In order to speak more precisely, therefore, we must recognize the importance of grouping or organizing the input sequence into units or chunks. Since the [working] memory span is a fixed number of chunks, we can increase the number of [binary] bits of information that it contains simply by building larger and larger chunks, each chunk containing more information than before.
>
> A man just beginning to learn radio-telegraphic code hears each dit and dah as a separate chunk. Soon he is able to organize these sounds into letters and then he can deal with the letters as chunks. Then the letters organize themselves as words, which are still larger chunks, and he begins to hear whole phrases.

Each of us has learned to deal with the limitations in our working memory. Still, in our roles as communicators and teachers, we often forget about the limitations of the student brains that are trying to receive and process the information we are communicating. I am reminded of presentations in which an overhead projector is used. With a click of a button a "page" of information is flashed up on the screen. The speaker makes some comments about this information, and then moves on to the next slide. Question: How much information should a slide display?

We want students to simultaneously read the slide's contents, listen to and process what is being said, and take notes! Think about the demands that this places on a brain's sensory and working memory capabilities. In my opinion, most speakers (most teachers) go far too fast.

For effective communication and learning, here is what needs to happen. An idea is presented both as a short line of text (perhaps accompanied with a graphical image) on a slide. Often the presenter speaks the words, so that the listener/viewer gets both a written and oral version, and perhaps a visual image version of the idea.

The presenter then presents some related ideas designed to help the students construct knowledge and understanding that ties in with their current knowledge and understanding. This might be via a sequence of examples, personal stories, and so on. In a teaching situation, the presenter may then provide time for students to talk together in small groups—such human to

human interaction helps students to better understand what has been presented and to gain insights about what one's fellow students are learning and understanding.

Somewhat the same ideas apply to designing effective Web pages. Jacob Nielsen is a world-class researcher in the design of Web pages. Quoting from his article, Short-term Memory and Web Usability (Nielsen, 12/7/09):

> The human brain is not optimized for the abstract thinking and data memorization that websites often demand. Many usability guidelines are dictated by cognitive limitations.
>
> People can't keep much information in their short-term memory. This is especially true when they're bombarded with multiple abstract or unusual pieces of data in rapid succession. Lest designers forget how easily users forget, let's review why our brains seem to be so weak.
>
> Human beings are remarkably good at hunting the woolly mammoth. Considering that we humans have neither fangs nor claws, our ancestors did fine work in exterminating most megafauna from Australia to North America armed with nothing better than flint weapons. (In today's more environmentally conscious world, we might deplore their slaughtering ways, but early humans were more interested in catching their dinner.)
>
> Many of the skills needed to use computers aren't highly useful in slaying mammoths. Such skills include remembering obscure codes from one screen to the next and interpreting highly abbreviated form-field labels. **It's no surprise that people are no good at these skills,** since they weren't important for survival in the ancestral environment. [Bold added for emphasis.]

Although Nielsen is writing about user interfaces in Web design, the same ideas hold for a teacher designing a teacher-to-student interface. The learning teaching/learning interface needs to be designed to effectively cope with limitations of the brain. Again quoting from Nielsen:

> Although the average human brain is better equipped for mammoth hunting than using websites, we're not all average. In fact, there are huge individual differences in user performance: the top 25% of users are 2.4 times better than the bottom 25%.

That fact is one of the major challenges in teaching. How does one teach a group of students whose brains contain that much brain variance?

Hippocampus and Long-term Memory

An intact human brain has two hippocampi, one in each side of the brain. The hippocampus belongs to the limbic system and plays important roles in the consolidation of information from short-term memory to long-term memory.

Quoting from PsycEducation.org:

> This part of the brain appears to be absolutely necessary for making new memories. If you didn't have it, you couldn't live in the present: you'd be stuck in the past of old memories. And this is common: Alzheimer's disease affects the hippocampus first and severely, before other parts of the cortex (later, the frontal lobes too). So memory is usually the first thing to start to falter in Alzheimer's — the ability to make new ones, that is. Who visited yesterday? Where did I put the car keys? Why isn't there any mail today (when you brought it in 3 hours ago)?

Modern brain-scanning equipment allows us to "see" what parts of the brain are most active when the brain performs various tasks. For example, quoting from Byrne (2009 to present):

> Figure 7.5 illustrates an example of a PET scan of an individual who is performing an object location test. The color code is such that the brighter, redder regions indicate increased brain activity. **The most active region is the hippocampus.** In discussions of memory, the hippocampus is mentioned repeatedly because it is a major part of the brain involved in declarative memory [long-term memory] function. [Bold added for emphasis.]

Henry Molaison (H.M.) had a bilateral medial temporal lobectomy to surgically remove the anterior two thirds of his hippocampi in an attempt to cure his epilepsy. Researchers studied his brain for many years after the operation, until he died. Quoting again from Byrne (2009 to present):

> Before the operation, H.M. had a fine memory, but after the operation, H.M. had a very severe memory deficit. Specifically, after the operation H.M.'s ability to form any new memories for facts and events was severely impaired; he had great difficulty learning any new vocabulary words; he could not remember what happened the day before. So if H.M. had an interview the day following a previous interview, he would have little or no memory about the interview or events during it. This study clearly indicated that the hippocampus was critical for memory formation. But whereas H.M. had great difficulty forming new memories for facts and events, he still had all of his old memories for facts and events. Specifically, he had all his childhood memories, and all of his memories prior to the operation.

Brain stimulation using electrical current to various parts of the brain has become both an important area of research and a new fad. Here is information about research on electrical stimulation of the hippocampus that improved learning. Quoting from Schmidt (2/8/2012):

> UCLA neuroscientists have demonstrated that they can strengthen memory in human patients by stimulating a critical junction in the brain. Published in the Feb. 9 edition of the New England Journal of Medicine, the finding could lead to a new method for boosting memory in patients with early Alzheimer's disease.
>
> The UCLA team focused on a brain site called the entorhinal cortex. Considered the doorway to the hippocampus, which helps form and store memories, the entorhinal cortex plays a crucial role in transforming daily experience into lasting memories.
>
> …
>
> "When we stimulated the nerve fibers in the patients' entorhinal cortex during learning, they later recognized landmarks and navigated the routes more quickly," Fried said. "They even learned to take shortcuts, reflecting improved spatial memory.
>
> "Critically, it was the stimulation at the gateway into the hippocampus — and not the hippocampus itself — that proved effective," he added.

There has been substantial research on how exercise benefits the brain. See, for example, (Chaddock, et al., 2010) and (Erickson, et al., 2009). Quoting from the Chaddock, et al. reference:

> **Exercise increases hippocampus size and improves memory.** One year of brisk walking by older adults caused their hippocampus to grow by 2 percent. They walked 40 minutes, three days a week. The control group that did not walk saw their hippocampus shrink by over 1 percent, due to normal aging.

Quoting from the Erickson, et al. reference:

> **Aerobic fitness is correlated with hippocampal size.** Physical fitness is directly associated with a larger hippocampus and better spatial memory in older adults. Participants in this study who were more fit were shown to have a significantly larger hippocampus. According to the study authors, "If you stay fit, you retain key regions of your brain involved in learning and memory."

Mirror Neurons: Monkey See, Monkey Do

Quoting from the Wikipedia

> A mirror neuron is a premotor neuron which fires both when an animal acts and when the animal observes the same action performed by another (especially conspecific) animal. Thus, the neuron "mirrors" the behavior of another animal, as though the observer were itself acting.… In humans, brain activity consistent with mirror neurons has been found in the premotor cortex and the inferior parietal cortex. Some scientists consider mirror neurons one of the most important findings of neuroscience in the last decade.

Mirror neurons have received quite a bit of publicity and perhaps have been over-hyped. A January 2005 NOVA broadcast contains an excellent 14-minute video about mirror neurons (NOVA, 2005).

Here is a very brief book suggestion quoted from an email message written by Robert Sylwester. He recommends *Mirroring People: The New Science of How We Connect with Others* by Marco Iacobonni (2008). Quoting from Sylwester's comments on the book:

> Within the brains of humans, apes, and monkeys is a small set of neurons that simulate the actions of others in real time. When you see Humphrey Bogart lock lips with Ingrid Bergman, the same brain cells fire as when you kiss your honey. When you hear co-workers crack open a soda, in your brain it's as if you'd opened the can yourself.
>
> Since their discovery in monkeys less than two decades ago, mirror neurons have been called into service to explain just about everything that makes us human--from empathy and language to politics and pornography. Are these cells really the be-all and end-all of human nature? In one of the first books on the subject, neuroscientist Marco Iacobonni clearly explains what we do know (and how) and what we don't know (and can't).
>
> Want to learn what mirror neurons have to do with Super Bowl commercials, violent video games, autism, addiction, and even free will? This is your book.

Gregory Hickok's book, *The Myth of Mirror Neurons: The Real Neuroscience of Communication and Cognition* (Hickok, 2014), questions some of the literature in the field of mirror neurons. Quoting from a review of Hickok's book by Bob Grant:

> Serving as a case study in how excitement about a scientific discovery can go astray, The Myth of Mirror Neurons relates the breathless exuberance that attended the identification of a new type of brain cell initially regarded as a revelation in our understanding of

> human brain function. University of California, Irvine, cognitive scientist Gregory Hickok throws cold water on the idea that mirror neurons, which were first observed in the motor cortex of macaques in the 1990s, are crucial to how the primate brain understands the actions of others.
>
> After their initial discovery, mirror neurons became neuroscience's cells du jour, with tons of papers throughout the 2000s exploring their role in social cognition, language, autism, and more. But the buzz about mirror neurons outpaced the science, according to Hickok. Journals published shoddy studies, and speculation about the ability of mirror neurons to inform the primate brain's "action understanding" ran amok. Since then, several neuroscientists, Hickok among them, have reevaluated the roles played by these neurons.
>
> Hickok doesn't simply destroy the hope surrounding mirror neurons; he points the way to new research directions that could more properly contextualize the function of the still-interesting brain cells.

You and Your Students

Even though the size of a six-year-old's brain is about 90% of what it be when the adult reaches full physical maturity, the six-year-old's brain will be steadily maturing for the next 20 years. As a teacher and/or a parent, you will contribute greatly to the eventual full functioning of this brain. So, what do you want to accomplish?

When they are quite young, children learn they have a brain and it is located in their head. They will gain some practical knowledge about paying attention, avoiding bumping their head on hard surfaces, the pain of a head ache, how it feels to not get enough sleep, and so on. However, they will likely learn little about the information in Chapter 2.

Select one of the sections of this chapter, such as Attention. What do want the slowly maturing child's brain to learn about "paying attention" and learning to control the focus of his or her attention? Or, think about how you use your communication skills in helping a child put information into his or her long-term memory in a manner that facilitates retrieval and use in solving challenging problems and accomplishing challenging tasks.

My suggestion is that you observe and think carefully about the learning that occurs as you interact with children of various ages (various levels of brain maturity). Don't just tell them something and later say, "I told you that before. Why don't you pay attention?" In the "telling" process, facilitate an interaction that helps lead to long term recall and understand-based use of what is being told.

References and Resources for Chapter 2

Byrne, J. (1997 to present). Chapter 7: Learning and memory. *Neuroscience Online.* Retrieved 8/18/2014 from http://neuroscience.uth.tmc.edu/s4/chapter07.html. Quoting from the chapter:

> The analysis of the anatomical and physical bases of learning and memory is one of the great successes of modern neuroscience. Thirty years ago little was known about how memory works, but now we know a great deal. This Chapter will discuss four issues that are central to learning and memory. First, what are the different types of memory? Second, where in the brain is memory located?… Third, how does memory work?…

Fourth, is the issue of importance to many people, especially as we age: How can memory be maintained and improved, and how can it be fixed when it is broken?

CDC (2015). My child has been diagnosed with ADHD—Now what? Centers for Disease Control and Prevention. Retrieved 5/1/2015 from http://www.cdc.gov/ncbddd/adhd/treatment.html. Quoting from the article:

> Research shows that behavioral therapy is an important part of treatment for children with ADHD. ADHD affects not only a child's ability to pay attention or sit still at school, it also affects relationships with family and how well they do in their classes.

Cooper-Kahn, J., & Diet, L. (2008). What is executive functioning? *LD Online.* Retrieved 5/1/2015 from http://www.ldonline.org/article/29122/. Quoting from the document:

> We believe that the focus on executive functioning represents a significant advancement in our understanding of children (and adults!) and their unique profile of strengths and weaknesses.

Douglas (2015). The science behind memory improvement. Retrieved 5/4/2015 from http://www.memory-improvement-tips.com/memory-research.html. Quoting from the site:

> This page lists memory research evidence that backs up much of the advice and techniques I explain on this website.… The rest of this site explains memory improvement habits and techniques.

Hickok, G. (2014). *The myth of mirror neurons: The real neuroscience of communication and cognition.* New York: W.W. Norton. Quoting from http://books.wwnorton.com/books/The-Myth-of-Mirror-Neurons/:

> The *Myth of Mirror Neurons* not only delivers an instructive tale about the course of scientific progress—from discovery to theory to revision—but also provides deep insights into the organization and function of the human brain and the nature of communication and cognition.

Iacoboni, M. (2008). *Mirroring people: The new science of how we connect with others.* New York: Farrar, Straus, & Giroux.

The first few chapter titles are: Neuro This; Brain Surprises; The Fab Four; Mirrors in the Brain; I know What You Are Doing; I Know What you are Thinking; I Can Hear What You are Doing; Mirroring Tool Use; and I Know That You are Copying Me.

Kandra, C. (n.d.) 11 great ways to improve your memory. *About Education.* Retrieved 5/4/2015 from http://psychology.about.com/od/memory/ss/11-Great-Ways-to-Improve-Your-Memory.htm. Quoting from the website:

> Before your next big exam, be sure to check out some of these tried and tested techniques for improving memory. These research-proven strategies can effectively improve memory, enhance recall, and increase retention of information.

Mayo Clinic Staff (2015). Attention-deficit/hyperactivity disorder (ADHD) in children. *Mayo Clinic*. Retrieved 5/2/2015 from http://www.mayoclinic.org/diseases-conditions/adhd/basics/symptoms/con-20023647. Quoting from the website:

Attention-deficit/hyperactivity disorder (ADHD) has been called attention-deficit disorder (ADD) in the past. But ADHD is now the preferred term because it describes both of the primary features of this condition: inattention and hyperactive-impulsive behavior.

Miller, G.A. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. Retrieved 12/7/09 from http://www.musanim.com/miller1956/.

This is a seminal research article about human short term. It is written in a somewhat folksy style. It begins with the statement:

My problem is that I have been persecuted by an integer. For seven years this number [seven plus or minus two] has followed me around, has intruded in my most private data, and has assaulted me from the pages of our most public journals.

Nielsen, J. (12/7/09). Short-term memory and web usability. *Nielsen Norman Group*. Retrieved 5/3/2015 from http://www.useit.com/alertbox/short-term-memory.html. Quoting from the website:

Short-term memory limitations dictate a whole range of other Web design guidelines [such as]:

- [Computer] response times must be fast enough that users don't forget what they're in the middle of doing while waiting for the next page to load.
- Change the color of visited links so that users don't have to remember where they've already clicked.
- Make it easy to compare products, highlighting the salient differences on both the initial category page and in special comparison views.

NOVA (2005). Mirror neurons. (Video, 14:00.) *NOVA Science Now.* Retrieved 6/12/2015 from http://www.pbs.org/wgbh/nova/body/mirror-neurons.html. Quoting from the website:

According to provocative discoveries in brain imaging, inside our heads we constantly "act out" and imitate whatever activity we're observing. As this video reveals, our so-called "mirror neurons" help us understand the actions of others and prime us to imitate what we see.

Posner, M. (2009). Implications of cognitive neuroscience for education. (Video, 19:58.) *GoCognitive.* Retrieved 7/5/2015 from http://www.gocognitive.net/video/michael-posner-implications-cognitive-neuroscience-education. Quoting from the website:

Dr. Michael Posner describes how general principles of brain development and brain function have been applied to educational practice. Dr. Posner specifically highlights the improved understanding of the cognitive processes in reading and executive attentional control as examples of how modern cognitive neuroscience can inform educational approaches.

Ricker, J. (n.d.). *PSY 101—Introduction to psychology.* Retrieved 5/2/2015 from http://sccpsy101.com/home/chapter-5/section-7/.

This six-chapter online book includes practice quizzes. Chapter 3 covers The Structures and Functions of the Brain. Chapter 5 covers Remembering and Forgetting.

Schwartz, K. (12/5/2013). Age of distraction: Why it's crucial for students to learn to focus. *Mind/Shift.* Retrieved 5/1/2015 from http://blogs.kqed.org/mindshift/2013/12/age-of-distraction-why-its-crucial-for-students-to-learn-to-focus/.

This article focuses on the work of Daniel Goleman. Quoting from the document:

> "Children I'm particularly worried about because the brain is the last organ of the body to become anatomically mature. It keeps growing until the mid-20s," Goleman said. If young students don't build up the neural circuitry that focused attention requires, they could have problems controlling their emotions and being empathetic.

Schwartz, S. (4/17/2015). Seven easy ways to boost your memory. *Grandparents.com.* Retrieved 4/27/2015 from http://www.huffingtonpost.com/2015/04/17/how-to-sharpen-your-memory_n_7041374.html?utm_hp_ref=brain.

The list includes use of caffeine, exercise, stopping smoking, and a sensible sleep schedule. I have a blog entry on this topic, and it is quite popular.

UCSF (n.d.). Frontotemporal dementia. *University of California, San Francisco.* Retrieved 5/1/2015 from http://memory.ucsf.edu/ftd/overview/biology/executive/single. Quoting from the document:

> By examining the impact of neurodegenerative disease, we can improve our understanding of how brain functions are organized. Although specific diseases are often noted for their effects in one area of function, we learn most about the brain's functions by comparing them across different diseases. (UCSF Memory and Aging Center.)

Chapter 3. The Changing Brain

> The young are heated by Nature as drunken men by wine.
> (Aristotle; Greek philosopher and scientist; 384-322 BCE.)

A typical human's brain reaches full maturity by about age 26. However, that is a misleading statement. Every thought you think and every piece of information you access in your brain produces changes in your brain. Memories weaken if they are not accessed from time to time. This is sometimes summarized by the statement, "Use it or lose it."

> Neuron: (also known as a nerve cell) is an electrically excitable cell that processes and transmits information through electrical and chemical signals.
>
> Dendrite: the bushy, branching extensions of a neuron that receive messages and conduct impulses toward the cell body/axon—the extension of a neuron, ending in branching terminal fibers, through which messages pass to other neurons….

Your brain contains approximately 87 billion neurons, having an average of 7,000 dendrites apiece. Most people find these large numbers incomprehensible. The number of neurons you have is well over ten times the number of humans on earth. The number of dendrites you have is well over 70,000 times the number of people on earth.

I strongly recommend that you view the first 11-minute section of the PBS video, Inside the Teenage Brain (*PBS FRONTLINE,* 2002). It provides an excellent introduction to the changing brain.

Daniel Golden has written a short article summarizing ways to help your brain grow more dendrites (Golden, n.d.). Quoting from the article:

> What can the average person do to strengthen his or her mind? "The important thing is to be actively involved in areas unfamiliar to you," says Arnold Scheibel, head of UCLA's Brain Research Institute. "Anything that's intellectually challenging can probably serve as a kind of stimulus for dendritic growth, which means it adds to the computational reserves in your brain." So pick something that's diverting and, most important, unfamiliar. A computer programmer might try sculpture; a ballerina might try marine navigation.

Nature and Nurture

Quoting from Kendra Cherry's article, What is Nature Versus Nurture? (Cherry, n.d.):

> **Nature** refers to all of the genes and hereditary factors that influence who we are – from our physical appearance to our personality characteristics.
>
> **Nurture** refers to all the environmental variables that impact who we are, including our early childhood experiences, how we were raised, our social relationships, and our surrounding culture.

If we pick a particular human trait such as personality or intelligence, we can ask and attempt to answer how much of the trait is determined by nature and how much by nurture. A common

approach is to study identical twins, fraternal twins, and non-twin siblings who are raised under varying circumstances. For example, one can study twins separated at birth.

If we define intelligence in terms of our available IQ tests, then we come to the conclusion for children that intelligence is approximately 40 to 50% determined by inheritance. However, such research studies indicate that nature and nurture are highly intertwined. Thus, for example, children learn the language or languages spoken in their environment. But, some children have more innate talent to learn languages than others. Linguistic intelligence is one of the multiple intelligences posited by Howard Gardner.

The pace of change brought on by nature varies from person to person. Pay special attention to the section on the Teenage Brain given later in this chapter. On average, girls begin the brain changes associated with adolescence much sooner than boys. Since the nurture (for example, home environment and travel experiences) that children grow up with varies considerably from child to child, at any particular grade level we see a compounding of changes wrought by nurture and by variations in nurturing.

In considering nature versus nurture in terms of intelligence, it is easy to forget how intelligent an average person is. Think for a bit about the amount of intellectual prowess it takes to carry on a conversation about a topic that interests you or to make plans about what you will do later in the day, and then carry out the plans.

Neurogenesis: Growing New Neurons

At one time brain researchers believed that neurogenesis (birth of neurons) did not occur in adult human brains. However, quoting from the Wikipedia:

> Neurogenesis (birth of neurons) is the process by which neurons are generated from neural stem cells and progenitor cells. Most active during pre-natal development, neurogenesis is responsible for populating the growing brain with neurons. Recently neurogenesis was shown to continue in several small parts of the [adult] brain of mammals: the hippocampus and the subventricular zone.

Kate Yandell's article, Lifelong Neuronal Rebirth, provides a good overview of adult neurogenesis (Yandell, 2/20/2014). Quoting from the article:

> Certain neurons in the human striatum—a brain region involved in movement and cognition—are renewed throughout life, according to a study published today (February 20, 2014) in Cell. At one time, researchers thought that human neurons regenerated in fewer brain regions than in rodents and nonhuman primates. Now it appears that regenerated neurons simply show up in different brain regions in humans compared with other mammals—a findings that has potential implications for the origins of learning and other higher-order cognitive processes.

It may turn out that deep brain stimulation (DBS) using electrical currents increases neuronal growth. Quoting from Szalavitz (9/28/2011):

> The current research in mice used Deep Brain Stimulation (DBS) in the entorhinal cortex, a brain area that interacts with a critical memory region called the hippocampus. …
>
> Researchers found that when the brain stimulators were turned on for one hour, the growth of new brain cells in a key region of the hippocampus nearly doubled.

Here is a challenging neuroscience question. How does your mind/brain distinguish between something it learned 15 seconds ago, 15 minutes ago, 15 hours ago, 15 days ago, 15 weeks ago, 15 months ago, and 15 years ago? If your memory was like a filing cabinet, each item could be date-stamped, and retrieval of a content item could be accompanied by retrieval of the exact time it was stored. But, your memory does not work that way. So, how does your mind/brain avoid getting confused by this "time" situation? A conjecture about a partial answer is given in the next two paragraphs.

An excellent discussion about growing new neurons is available in William Skaggs' *Scientific American* article, New Neurons for New Memories (Skaggs, September, 2014). Research on neuronal growth in the hippocampus may help to explain how the brain keeps separate memories separate. Quoting from the article:

> Neuroscientists now suspect that neurons born in the hippocampus help the brain create and sift through the millions of memories we form over the course of a lifetime. If this is true, neurogenesis might solve a puzzle that has perplexed memory researchers for more than 60 years: how our brain keeps separate memories of similar events. These discoveries may ultimately reveal not only how we recall the episodes of our lives but also how we can preserve our brain's powerful record-keeping faculties despite the inevitable decline of aging.

Think about the possibilities if researchers are able to foster/promote/cause the growth of new neurons in the various parts of the brain. The implications for people with brain injuries and brain degenerative diseases are immense.

But, what if we reach a time when we can do something akin to "blood doping"—that is, "neuron doping or DBS?" Right now we test athletes for use of "illegal" drugs. Hmm. Perhaps we will eventually want to test students for use of procedures that increase their number of neurons? But, how can we possibly test whether students are "self medicating" with DBS, using inexpensive equipment they have built for themselves?

Neuroplasticity

Quoting from the Wikipedia:

> Neuroplasticity, also known as brain plasticity, is an umbrella term that encompasses both synaptic plasticity and non-synaptic plasticity—it refers to changes in neural pathways and synapses which are due to changes in behavior, environment, and neural processes, as well as changes resulting from bodily injury.

During the past decade brain science researchers have made major progress in understanding brain plasticity. If you are just getting started in learning about this topic, I highly recommend you view Michael Merzenich's *TED Talks,* Growing Evidence of Brain Plasticity (Merzenich, 2004). His entertaining and insightful presentation captures a major change that was going on in brain science late in the 20th century and early in the 21st century. It was becoming generally accepted that adult brains have amazing plasticity and ability to change.

However, the history of brain plasticity goes back many years before that time. Quoting from the Wikipedia:

> Psychologist William James suggested that the brain was perhaps not as unchanging as previously believed way back in 1890. In his [1890] book The Principles of Psychology,

> he wrote, "Organic matter, especially nervous tissue, seems endowed with a very extraordinary degree of plasticity." However, this idea went largely ignored for many years.
>
> In the 1920s, researcher Karl Lashley provided evidence of changes in the neural pathways of rhesus monkeys. By the 1960s, researchers began to explore cases in which older adults who had suffered massive strokes were able to regain functioning, demonstrating that the brain was much more malleable than previously believed. Modern researchers have also found evidence that the brain is able to rewire itself following damage.

Huntington's Outreach Project for Education at Stanford (HOPES) is a team of faculty and undergraduate students at Stanford University dedicated to making scientific information about Huntington's disease (HD) more readily accessible to the public. Some of their work is presented in Stephanie Liou's paper on Neurobiology (Liou, 5/26/010). Quoting from this paper:

> Conditions in our environment, such as social interactions, challenging experiences and even fresh air can play a crucial role in brain cell survival and the formation of connections. Just as the brain changes in response to environmental conditions, it can also change and rearrange in response to injury or disease. Commonly, these rearrangements involve changes in the connection between linked nerve cells, or neurons, in the brain. Brain reorganization takes place by mechanisms such as "axonal sprouting", where undamaged axons grow new nerve endings to reconnect the neurons, whose links were severed through damage. Undamaged axons can also sprout nerve endings and connect with other undamaged nerve cells, thus making new links and new neural pathways to accomplish what was a damaged function. For example, although each brain hemisphere has its own tasks, if one brain hemisphere is damaged, the intact hemisphere can sometimes take over some of the functions of the damaged one. Flexible and capable of such adaptation, the brain compensates for damage in effect by reorganizing and forming new connections between intact neurons. The brain can also respond to a deficiency in one type of sensory input by enhancing the processing of other sensory inputs. In blind individuals, for instance, areas of the cortex normally assigned to visual processing can adapt to process completely different sensory inputs, such as hearing or touch.

Two Hemispheres

A human brain has two hemispheres. They communicate through a brain bundle called the corpus callosum. Quoting from Chapter 7 of David Hubel's online book, *Eye, Brain, and Vision* (Hubel, 1995):

> Until about 1950 the function of the corpus callosum was a complete mystery. On rare occasions, the corpus callosum in humans is absent at birth, in a condition called agenesis of the corpus callosum. Occasionally it may be completely or partially cut by the neurosurgeon, either to treat epilepsy (thus preventing epileptic discharges that begin in one hemisphere from spreading to the other) or to make it possible to reach a very deep tumor, such as one in the pituitary gland, from above. In none of these cases had neurologists and psychiatrists found any deficiency….

Many of important organs are duplicated in a human body. We have two eyes, two ears, two kidneys, two lungs, two arms, and two legs. Thus, we tend to take it for granted that our brain has two somewhat independently functioning hemispheres. Certainly the two hemispheres are

not identical. However, it is possible to function reasonably well on just one of them. Quoting from the Wikipedia:

> This [hemispherectomy] procedure is almost exclusively performed in children because their brains generally display more neuroplasticity, allowing neurons from the remaining hemisphere to take over the tasks from the lost hemisphere. This likely occurs by strengthening neural connections which already exist on the unaffected side but which would have otherwise remained small in a normally functioning, uninjured brain.
>
> In one study of children under 5 who had this surgery to treat catastrophic epilepsy, 73.7% were freed of all seizures. Studies have found no significant long-term effects on memory, personality, or humor, and minimal changes in cognitive function overall. For example, one case followed a patient who had completed college, attended graduate school and scored above average on intelligence tests after undergoing this procedure at age 5.5.

Researchers have delved into the evolution of this two-hemispheres brain. Quoting from (MacNeilage, et al., July, 2009):

> The division of labor by the two cerebral hemispheres—once thought to be uniquely human—predates us by half a billion years. Speech, right-handedness, facial recognition and the processing of spatial relations can be traced to brain asymmetries in early vertebrates.
>
> The left hemisphere of the human brain controls language, arguably our greatest mental attribute. It also controls the remarkable dexterity of the human right hand. The right hemisphere is dominant in the control of, among other things, our sense of how objects interrelate in space.
>
> …
>
> Here we present evidence for a radically different hypothesis that is gaining support, particularly among biologists. The specialization of each hemisphere in the human brain, we argue, was already present in its basic form when vertebrates emerged about 500 million years ago.
>
> We suggest that the more recent specializations of the brain hemispheres, including those of humans, evolved from the original ones by the Darwinian process of descent with modification. (In that process, capabilities relevant to ancient traits are changed or co-opted in the service of other developing traits.) Our hypothesis holds that the left hemisphere of the vertebrate brain was originally specialized for the control of well-established patterns of behavior under ordinary and familiar circumstances. In contrast, the right hemisphere, the primary seat of emotional arousal, was at first specialized for detecting and responding to unexpected stimuli in the environment.

Differences in the Male and Female Brains

Substantial progress is occurring in identifying differences in human female and male brains. Mo Costandi's article, Male Brain Versus Female Brain: How Do They Differ?, contains a good discussion of some of the latest findings (Costandi, 10/6/2013). Quoting from the article:

> Subtle observable differences exist between male and female brains, but how exactly these relate to differences in behaviour is unknown. Such gender variations in the brain

> are often exaggerated and misappropriated, not only by the mass media but also by scientists, to reinforce stereotypes and perpetuate myths.…
>
> The most obvious difference between the brains of men and women is overall size – men's brains are, on average, between 10 and 15 per cent larger than women's. In one recent study, neuroscientists compared the brains of 42 men and 58 women postmortem, and found that men's weighed an average of 1,378g (3lb), compared with 1,248g (2.75lb) for women. These size differences have been found repeatedly, but they emerge only when comparing large numbers of people, so some women's brains are larger than the average [man] whereas some men's are smaller [than the average woman]. **These differences partly reflect the fact that men are generally bigger and taller than women, but they are not related to differences in intelligence.**
>
> Men and women's brains also differ in overall composition. Male brains tend to have a slightly higher proportion of white matter, whereas those of females have a higher proportion of grey matter in most parts of the cerebral cortex. Consequently, the cortex is slightly thicker in women's brains than in men's and, according to several studies, is slightly more convoluted as well. There are also sex differences in the size of individual brain structures. The hippocampus, a structure involved in memory formation, is on average larger in men than in women, as is the amygdala, which is also involved in memory, as well as emotions. [Bold added for emphasis.]

For some reason people (perhaps, men in particular) do considerable stereotyping of differences between males and females. Continuing to quote from Costandi:

> Numerous studies show subtle differences in male and female behaviour and in cognitive functions, too. Men tend to be more aggressive and outperform women on mental tasks involving spatial skills such as mental rotation, whereas women tend to be more empathetic and perform better on verbal memory and language tasks. Findings like these are often exaggerated to reinforce the stereotypes that women are bad at reverse parking and that they love to chat!

Capability in mathematics provides a good example of stereotyping. It used to be commonly accepted that men are better then women at math. Alice Park summarizes the school performance of girls versus boys in her article, Girls Beat Boys in Every Subject, and They Have for a Century (Park, 4/29/2014). Quoting from the article:

> Stereotypes are hard to break, and when it comes to education and gender, parents — and students — stick with a firmly held belief that girls don't do as well in math and science, while boys don't have great language and reading skills.
>
> But a review of 308 studies involving more than 1.1 million boys and girls who were students from 1914 to 2011 blows apart that idea. For 100 years, according to the data that included students from 30 countries, girls have been outperforming boys in all of their classes — reading, language and math and science. And they've been doing it throughout their academic careers, from elementary school to high school.

Teenage Brains

My 5/10/2015 Google search of *teenage brains* produced over seven million hits. Brain development starts before birth and continues until full brain maturity is reached at about age 25 to 26. Parents who have raised children to adulthood recognize that, during their teens, many

children became "sort of weird." The *National Geographic* article, Beautiful Brains*,* by David Dobbs help to explain this (Dobbs, October, 2001). Quoting from the article.

> The first full series of scans of the developing adolescent brain—a National Institutes of Health (NIH) project that studied over a hundred young people as they grew up during the 1990s—showed that our brains undergo a massive reorganization between our 12th and 25th years. The brain doesn't actually grow very much during this period. It has already reached 90 percent of its full size by the time a person is six, and a thickening skull accounts for most head growth afterward. But as we move through adolescence, the brain undergoes extensive remodeling, resembling a network and wiring upgrade.
>
> …
>
> These studies help explain why teens behave with such vexing inconsistency: beguiling at breakfast, disgusting at dinner; masterful on Monday, sleepwalking on Saturday. Along with lacking experience generally, they're still learning to use their brain's new networks. Stress, fatigue, or challenges can cause a misfire. Abigail Baird, a Vassar psychologist who studies teens, calls this neural gawkiness—an equivalent to the physical awkwardness teens sometimes display while mastering their growing bodies.

Sarah-Jayne Blakemore's *TED Talks,* The Mysterious Workings of the Adolescent Brain, focuses on the social brain of adolescents. (Blakemore, June, 2012). Quoting from the video:

> So adolescence is defined as the period of life that starts with the biological, hormonal, physical changes of puberty and ends at the age at which an individual attains a stable, independent role in society. It can go on a long time. One of the brain regions that changes most dramatically during adolescence is called prefrontal cortex.… Prefrontal cortex is an interesting brain area. It's proportionally much bigger in humans than in any other species, and it's involved in a whole range of high level cognitive functions, things like decision-making, planning, planning what you're going to do tomorrow or next week or next year, inhibiting inappropriate behavior, so stopping yourself saying something really rude or doing something really stupid. It's also involved in social interaction, understanding other people, and self-awareness.
>
> So MRI studies looking at the development of this region have shown that it really undergoes dramatic development during the period of adolescence. So if you look at gray matter volume, for example, gray matter volume across age from age four to 22 years increases during childhood, which is what you can see on this graph. It peaks in early adolescence. The arrows indicate peak gray matter volume in prefrontal cortex. **You can see that that peak happens a couple of years later in boys relative to girls, and that's probably because boys go through puberty a couple of years later than girls on average….** [Bold added for emphasis.]

Pay particular attention to last sentence in the quote. On average, there is a substantial difference between the brains of boys and the brains of girls during this puberty time period.

The National Institute of Mental Health has published The Teen Brain: Still Under Construction (NIH, 2011). Quoting from the document:

> An understanding of how the brain of an adolescent is changing may help explain a puzzling contradiction of adolescence: young people at this age are close to a lifelong peak of physical health, strength, and mental capacity, and yet, for some, this can be a

> hazardous age. Mortality rates jump between early and late adolescence. Rates of death by injury between ages 15 to 19 are about six times that of the rate between ages 10 and 14. Crime rates are highest among young males and rates of alcohol abuse are high relative to other ages. Even though most adolescents come through this transitional age well, it's important to understand the risk factors for behavior that can have serious consequences. Genes, childhood experience, and the environment in which a young person reaches adolescence all shape behavior. Adding to this complex picture, research is revealing how all these factors act in the context of a brain that is changing, with its own impact on behavior.
>
> …
>
> The assumption for many years had been that the volume of gray matter was highest in very early childhood, and gradually fell as a child grew. The more recent scans, however, revealed that the high point of the volume of gray matter occurs during early adolescence.
>
> While the details behind the changes in volume on scans are not completely clear, the results push the timeline of brain maturation into adolescence and young adulthood. In terms of the volume of gray matter seen in brain images, the brain does not begin to resemble that of an adult until the early 20s.

The Aging Brain and Dementia

An adult human brain declines in its capabilities as it grows older. The rate of decline varies considerably among different people, and it a product of both nature and nurture. Here is a definition of dementia from the Mayo Clinic:

> Dementia isn't a specific disease. Instead, dementia describes a group of symptoms affecting memory, thinking and social abilities severely enough to interfere with daily functioning.
>
> Dementia indicates problems with at least two brain functions, such as memory loss and impaired judgment or language, and the inability to perform some daily activities such as paying bills or becoming lost while driving.
>
> Though memory loss generally occurs in dementia, memory loss alone doesn't mean you have dementia. There is a certain extent of memory loss that is a normal part of aging.

Alzheimer's disease is particularly devastating type of dementia and is a major problem throughout the world. Alzheimer's is the most common cause of dementia, among people aged 65 and older.

Quoting from the Alzheimer's Foundation of America:

> Alzheimer's disease is a progressive, degenerative disorder that attacks the brain's nerve cells, or neurons, resulting in loss of memory, thinking and language skills, and behavioral changes.
>
> These neurons, which produce the brain chemical, or neurotransmitter, acetylcholine, break connections with other nerve cells and ultimately die. For example, short-term memory fails when Alzheimer's disease first destroys nerve cells in the hippocampus, and language skills and judgment decline when neurons die in the cerebral cortex.

There is substantial ongoing research on how to detect, prevent, delay, and treat Alzheimer's disease. Researchers at Ohio State University's Wexner Medical Center have developed SAGE, a pen-and-paper self-assessment dementia test (OSU Department of Neurology, n.d.). Quoting from the OSU website:

> Dr. Douglas Scharre, a neurologist at the Ohio State University Medical Center, developed the **Self-Administered Gerocognitive Examination (SAGE)** to help identify individuals with mild thinking and memory impairments at an early stage. The research shows four out of five people (80 percent) with mild thinking and memory (cognitive) issues will be detected by this test, and 95% of people who are normal thinking will have normal SAGE scores.
>
> Many of the assessment tools for cognitive disorders being used today, while accurate, have aspects that deter their use. "Seldom are physicians reimbursed for the time and effort it takes to give such tests, or they tie up personnel to physically administer the test," said Scharre, who advocates the use of routine screening for cognitive disorders in the primary care setting. [Bold added for emphasis.]

The OSU website contains a short video, Pen-and-Paper Test May Help Spot Alzheimer's Early, that describes SAGE. For more information see Scharre's article, Self-administered Gerocognitive Examination (SAGE): A Brief Cognitive Assessment Instrument for Mild Cognitive Impairment (MCI) and Early Dementia. (Scharre, D.W., et al., January/March, 2010).

Chapter 8 contains an extensive section on the aging brain.

Exercise and the Brain

My 5/10/2015 Google search of *exercise and the brain* produced about 180 million results. Exercise helps both your physical body and your brain/mind. Quoting from Heidi Godman's article, Regular Exercise Changes the Brain to Improve Memory, Thinking Skills (Godman, 4/9/2014):

> There are plenty of good reasons to be physically active. Big ones include reducing the odds of developing heart disease, stroke, and diabetes. Maybe you want to lose weight, lower your blood pressure, prevent depression, or just look better. Here's another one, which especially applies to those of us (including me) experiencing the brain fog that comes with age: exercise changes the brain in ways that protect memory and thinking skills. …
>
> Many studies have suggested that the parts of the brain that control thinking and memory (the prefrontal cortex and medial temporal cortex) have greater volume in people who exercise versus people who don't. "Even more exciting is the finding that engaging in a program of regular exercise of moderate intensity over six months or a year is associated with an increase in the volume of selected brain regions," says Dr. Scott McGinnis, a neurologist at Brigham and Women's Hospital and an instructor in neurology at Harvard Medical School.

Click here for an *IAE Blog* entry discussing physical exercise and the human brain. In brief summary, physical exercise is good for your brain. Schools that are cutting down on recess for students are undermining this important, research-based finding. A recent study reports on the value of exercise to both boys and girls, but indicated boys benefit more than girls. Substantial research supports the value of older adults remaining physically fit.

Douglas (2014) is a website providing a number of links to websites discussing how to improve memory. Typically, Douglas provides a brief "tidbit" and a citation. Here are three sample tidbits from this website:

- Exercise increases hippocampus size and improves memory. One year of brisk walking by older adults caused their hippocampus to grow by 2 percent. They walked 40 minutes, three days a week. The control group that did not walk saw their hippocampus shrink by over 1 percent, due to normal aging.
- Physically fit children perform better on memory tests. Children age 9 and 10 who were more physically fit had a 12 percent bigger hippocampus and scored higher on a test of relational memory (the memory-associated ability to relate and integrate information). Fitness was measured by how efficiently the student's body used oxygen while running on a treadmill ("the gold standard measure of fitness"). The size of their hippocampus was measured by MRI scan.
- Aerobic fitness is correlated with hippocampal size. Physical fitness is directly associated with a larger hippocampus and better spatial memory in older adults. Participants in this study who were more fit were shown to have a significantly larger hippocampus.

You and Your Students

This chapter introduces a huge amount of information useful to teachers, parents, and students. Do you work with teenagers? Then you can help them understand how/why their brain is different than it was before they entered puberty, and how it will change as their grows to full maturity by about age 25 or so. This type of information makes a great topic for small group discussions in health and science classes, as well as between parents and their children at home.

We and many of our students know older people who are suffering from dementia. Dementia, such as Alzheimer's, is quite frightening to children who witness it. This situation provides a good opportunity for children to learn about empathy and compassion from their parents and caregivers.

All children and adults can understand the values of regular physical exercise While students can easily see how such exercise helps their physical prowess, they may be surprised to learn how it helps their brain/mind capabilities.

References and Resources for Chapter 3

Blakemore, S. (June, 2012). The mysterious workings of the adolescent brain. (Video, 14:26.) *TED Talks*. Retrieved 5/10/2015 from http://www.ted.com/talks/sarah_jayne_blakemore_the_mysterious_workings_of_the_adolescent_brain. Quoting from the website:

> Why do teenagers seem so much more impulsive, so much less self-aware than grown-ups? Cognitive neuroscientist Sarah-Jayne Blakemore compares the prefrontal cortex in adolescents to that of adults, to show us how typically "teenage" behavior is caused by the growing and developing brain.

Cherry, K (n.d.). What is nature versus nurture? *About Education*. Retrieved 5/8/2015 from http://psychology.about.com/od/nindex/g/nature-nurture.htm. Quoting from the article:

> What researchers do know is that the interaction of heredity and environment is often the most important factor of all. Kevin Davies of PBS's *Nova* described on fascinating example of this phenomenon. Perfect pitch is the ability to detect the pitch of a musical tone without any reference.

Costandi, M. (10/6/2013). Male brain versus female brain: How do they differ? *Science.* Retrieved 5/9/2015 from http://www.theguardian.com/science/neurophilosophy/2013/oct/06/male-brain-versus-female-brain.

The *Science* article consists of parts of Mo Costandi's book, *50 Human Brain Ideas You Really Need to Know*. Quoting Costandi:

> [In the 50 short chapters of this 200-page book] I have covered what I believe to be many of the concepts that are fundamental to our current understanding of that wondrous lump of electrochemical jelly inside our heads.

Dobbs, D. (October, 2011). Beautiful brains. *National Geographic.* Retrieved 5/10/2015 from http://ngm.nationalgeographic.com/2011/10/teenage-brains/dobbs-text. Quoting from the Dobbs article:

> [My teenage son's] adventure raised the question long asked by people who have pondered the class of humans we call teenagers: What on Earth was he doing? Parents often phrase this question more colorfully. Scientists put it more coolly. They ask, What can explain this behavior?

Douglas (2014). The science behind memory improvement. Retrieved 5/10/2015 from http://www.memory-improvement-tips.com/memory-research.html. Quoting from the website:

> There has always been too much hype associated with memory improvement. It's easy to find "snake oil salesmen" selling magic pills they say give anyone a perfect memory. But you want good reasons for what you do, and so do I. Thus the importance of scientific research.

Godman, H. (4/9/2014). Regular exercise changes the brain to improve memory, thinking skills. *Harvard Health Publications.* Retrieved 5/10/2015 from http://www.health.harvard.edu/blog/regular-exercise-changes-brain-improve-memory-thinking-skills-201404097110. Quoting from the document:

> In a study done at the University of British Columbia, researchers found that regular aerobic exercise, the kind that gets your heart and your sweat glands pumping, appears to boost the size of the hippocampus, the brain area involved in verbal memory and learning. Resistance training, balance and muscle toning exercises did not have the same results.

Golden, D. (n.d.). How to make your dendrites grow and grow. San Diego Brain Injury Foundation. Retrieved 5/8/2015 from http://www.sdbif.org/Newsletter/Article16.htm. Quoting from the article:

> And remember, researchers agree that it's never to late. Says Scheilbel [head of UCLA's Brain Research Institute], "All of life should be a learning experience, not just for the

trivial reasons but because by continuing the learning process, we are challenging our brain and therefore building brain circuitry. Literally. This is the way the brain operates."

Hubel, D. (1995). *Eye, brain, and vision.* Retrieved 5/9/2015 from http://hubel.med.harvard.edu/book/bcontex.htm. Quoting from the Preface:

> This book is mainly about the development of our ideas on how the brain handles visual information; it covers roughly the period between 1950 and 1980.

Liou, S. (6/26/2010). Neurobiology. Huntington's outreach project for education at Stanford. Retrieved 5/9/2015 from http://web.stanford.edu/group/hopes/cgi-bin/hopes_test/neuroplasticity/. Quoting from the article:

> Research in the area of neurogenesis has resulted in an exciting recent discovery bearing on Huntington's Disease (HD). By studying post-mortem brains of people with HD, researchers at the University of Auckland in New Zealand found evidence suggesting that HD-affected brains produce new neurons throughout the course of the disease.

MacNeilage, P.F., Rogers, J., & Vallortigara, G. (July, 2009). Evolutionary origins of your right and left brain. *Scientific American.* Retrieved 6/20/09: http://www.scientificamerican.com/article.cfm?id=evolutionary-origins-of-your-right-and-left-brain. Quoting from the website:

> The division of labor by the two cerebral hemispheres—once thought to be uniquely human—predates us by half a billion years. Speech, right-handedness, facial recognition and the processing of spatial relations can be traced to brain asymmetries in early vertebrates.

Merzenich, M. (2004). Growing evidence of brain plasticity. (Video, 23:07.) *TED Talks.* Retrieved 5/9/2015 from http://www.ted.com/talks/michael_merzenich_on_the_elastic_brain?language=en.

> In this video, Neuroscientist Michael Merzenich looks at one of the secrets of the brain's incredible power: its ability to actively re-wire itself. He's researching ways to harness the brain's plasticity to enhance our skills and recover lost function.

NIH (2011). The teen brain: Still under construction. National Institute of Mental Health. Retrieved 5/10/2015 from http://www.nimh.nih.gov/health/publications/the-teen-brain-still-under-construction/index.shtml. Quoting from the document:

> One of the ways that scientists have searched for the causes of mental illness is by studying the development of the brain from birth to adulthood. Powerful new technologies have enabled them to track the growth of the brain and to investigate the connections between brain function, development, and behavior.

OSU Department of Neurology (n.d.). OSU researchers design self-test for memory disorders. Ohio State University Wexner Medical Center. Retrieved 6/15/2015 from http://neurology.osu.edu/sagetest.html. Quoting from the website:

> The handwritten self-assessment, which can take less than 15 minutes to complete, is a reliable tool for evaluating cognitive abilities. Findings confirming the validity of the tool are reported in the current issue of the journal Alzheimer Disease and Associated Disorders website at

http://journals.lww.com/alzheimerjournal/Abstract/2010/01000/Self_administered_Gerocognitive_Examination.9.aspx.

The OSU website contains a video: Pen-and-paper test may help spot Alzheimer's early. (Video, 1:43.) Retrieved 6/13/2015 from http://neurology.osu.edu/sagetest.html.

Also see Scharre, D.W., et al. (January/March, 2010) listed below.

Park, A. (4/29/2014): Girls beat boys in every subject, and they have for a century. *Time.* Retrieved 5/9/2015 from http://time.com/81355/girls-beat-boys-in-every-subject-and-they-have-for-a-century/. Quoting from the article:

> "We didn't expect to find that girls did better at math and science as well," says Daniel Voyer, professor of psychology, who published his results in the American Psychological Association journal Psychological Bulletin. "The girls did better whatever you give them."

PBS FRONTLINE (2002). Inside the teenage brain. *PBS FRONTLINE.* (Video, 60:00.) Retrieved 5/10/2015 from http://www.pbs.org/wgbh/pages/frontline/shows/teenbrain/view/. Quoting from the website:

> In "Inside the Teenage Brain," FRONTLINE chronicles how scientists are exploring the recesses of the brain and finding some new explanations for why adolescents behave the way they do. These discoveries could change the way we parent, teach, or perhaps even understand our teenagers.

Scharre, D.W., et al. (January/March, 2010). Self-administered Gerocognitive Examination (SAGE): A brief cognitive assessment instrument for mild cognitive impairment (MCI) and early dementia. *Alzheimer Disease and Associated Disorders.* Retrieved 6/15/2015 from http://journals.lww.com/alzheimerjournal/Abstract/2010/01000/Self_administered_Gerocognitive_Examination.9.aspx. Quoting from the abstract:

> Conclusions: This study suggests that SAGE is a reliable instrument for detecting cognitive impairment and compares favorably with the MMSE [Mini-Mental State Examination]. The self-administered feature may promote cognitive testing by busy clinicians prompting earlier diagnosis and treatment.

Skaggs, W. (September/October, 2014). New neurons for new memories. *Scientific American.* Retrieved 5/8/2015 from: http://www2.centralcatholichs.com/copied%20articles%20to%20review/Neuro/new%20neurons%20and%20memories%20SAM%20sep%2014.pdf.

How does the brain remember and distinguish between quite similar events that occur at different places and/or times, without getting them mixed up? This is a challenging research problem.

Szalavitz, M. (9/28/2011). Could deep brain stimulation fend off Alzheimer's? *Time.* Retrieved 5/8/2015 from http://healthland.time.com/2011/09/28/could-deep-brain-stimulation-fend-off-alzheimers/. Quoting from the article:

> More than 60,000 patients with Parkinson's, along with those with treatment-resistant cases of depression and severe obsessive-compulsive disorder, have been treated with

DBS. Could it help some of the 5 million Americans — 13% of the population over 65 — living with Alzheimer's?

Yandell, K. (2/20/2014). Lifelong neuronal rebirth. *The Scientist.* Retrieved 2/22/2014 from http://www.the-scientist.com//?articles.view/articleNo/39238/title/Lifelong-Neuronal-Rebirth/. Quoting from the article:

> "This is the clearest demonstration that [adult neurogenesis in the striatum] is happening in humans," said Arnold Kriegstein, a developmental neurobiologist at the University of California, San Francisco, who was not involved in the study. "It reenergizes the notion that . . . in the future, it would be possible to harness these cells in some way to repair the injured brain."

Chapter 4. Three Brains: Human, Reading/Writing, and Computer

> "The real problem is not whether machines think but whether men do." (B. F. Skinner; American psychologist; 1904-1990.)
>
> "Computers are incredibly fast, accurate, and stupid. Human beings are incredibly slow, inaccurate, and brilliant. Together they are powerful beyond imagination." (Leo Cherne; American economist, public servant and commentator; 1912-1999.)

You might wonder why a book about the human brain contains a chapter focusing on two non-human brains. Three good reasons for this are:

1. Reading and writing are in some sense a type of human-created aid to human intelligence. Five thousand years of use of this auxiliary brain—an aid to our intelligence—has led to the development of electronic digital computers.
2. Progress in artificial intelligence (machine intelligence) has helped us to better understand the human brain. As with many areas in science, computer modeling of the "real thing" helps us to better understand the real thing.
3. We are making significant progress in human-brain-to-computer-brain interfaces. In essence, some of this progress makes a computer brain into an electronically connected extension of the human brain. See some examples in Eric Leuthardt's five-minute video Mind, Powered (Leuthardt, 11/1/2014).

Reading and Writing

Think about the invention of reading and writing. Reading and writing are a type of extension of the human brain, and they certainly changed the cognitive capabilities of humans. Computer technology incorporates reading and writing, and adds a great many other aids to human mind/brain capabilities.

As far as researchers are able to determine, humans had a well-developed system of oral communication before they began to draw/paint pictures on cave walls more than 40,000 years ago. Such cave wall images are a precursor to reading and writing. They capture information that can be visually passed on from generation to generation.

The Ishango bones that contain a pattern of notches have been dated to about 20,000 years ago, and can be considered to be a type of math-oriented written communication.

Clay tokens dating back about 10,000 years are a precursor to writing. A token with the image of a sheep was used to represent a sheep. The idea and use of clay tokens eventually led to the use of sequences of symbols impressed into clay or chiseled into stone. Quoting from the Wikipedia:

> It is generally agreed that true writing of language (not only numbers) was invented independently in at least two places: Mesopotamia (specifically, ancient Sumer) around

> 3200 BCE and Mesoamerica around 600 BCE. Several Mesoamerican scripts are known, the oldest being from the Olmec or Zapotec of Mexico.
>
> It is debated whether writing systems were developed completely independently in Egypt around 3200 BCE and in China around 1200 BCE, or whether the appearance of writing in either or both places was due to cultural diffusion (i.e. the concept of representing language using writing, if not the specifics of how such a system worked, was brought by traders from an already-literate civilization).

Reading and writing are one of humanity's greatest inventions. The importance of reading and writing has gradually grown over the past 5,000 years, and they are now well-accepted as an indispensable component of a modern education.

The innate human brain and our physical capabilities for speaking and listening laid a foundation for reading and writing. But, reading and writing are not as easily learned as speaking and listening. In addition, research into dyslexia indicates that, in terms of learning to read, some human brains are wired quite differently than others, and this can make it especially difficult for some people to learn to read. Read about dyslexia in Chapter 7.

Judy Willis is a classroom teacher turned cognitive neuroscientist. A interview by her is reported in the article, Writing and the Brain: Neuroscience Shows the Pathways to Learning (National Writing Project, 5/3/2011). Quoting from the article:

> **NWP:** As science, technology, engineering, and mathematics (STEM) subjects get more emphasis, it seems as if writing and the arts have become secondary. Where do you see writing's place in STEM subjects?
>
> **Willis:** It's interesting because the increasing buzz about an innovation crisis in the STEM subjects comes at a time when neuroscience and cognitive science research are increasingly providing information that correlates creativity with intelligence; academic, social, and emotional success; and the development of skill sets and higher-process thinking that will become increasingly valuable for students of the 21st century.
>
> Consider all of the important ways that writing supports the development of higher-process thinking: conceptual thinking; transfer of knowledge; judgment; critical analysis; induction; deduction; prior-knowledge evaluation (not just activation) for prediction; delay of immediate gratification for long-term goals; recognition of relationships for symbolic conceptualization; evaluation of emotions, including recognizing and analyzing response choices; and the ability to recognize and activate information stored in memory circuits throughout the brain's cerebral cortex that are relevant to evaluating and responding to new information or for producing new creative insights—whether academic, artistic, physical, emotional, or social.

Reading and writing can be thought of as a technology-based interface between human brains. Historically, reading and writing made use of quite simple technology. The mass production of paper, the printing press, eyeglasses, and the telegraph all contributed to this form of communication. Computer technology has brought us word processors, spelling and grammar checkers, email, the Web, search engines, speech-to-text and text-to-speech systems, and language translation systems. There are powerful aids to communication via reading and writing!

Technological Mini-singularities in Education

The steadily increasing capabilities of computer intelligence has been featured in many popular media publications in recent years. Quoting from (Moursund, 5/16/2015):

> The term *singularity* has different meanings in different disciplines. For example, physicists consider a black hole to be a singularity. Mathematicians think about the function f(x) = 1/x and say that the point x = 0 is a singularity. (Division by zero is a "no-no" in math.)
>
> In computer technology, **the** singularity is when computers become more intelligent than people. I have written about this idea in the articles (Moursund, 3/5/2015 and 2/25/2015).
>
> Of course, we don't know when—if ever—computers will become more intelligent than people. But, some people like to speculate about that possibility. They note that artificially intelligent computers and robots are steadily becoming more capable. They point to examples where, in an increasing number of problem-solving and task-accomplishing situations, computers and robots already are more capable than people.
>
> Notice that in the previous paragraph I used the term more capable rather than more intelligent. I use the term capable to refer to the ability to solve problems and accomplish tasks. That is quite different from being intelligent. A computer can accurately add a list of a million integers in less than a second. This does not in any sense say that the computer is intelligent.
>
> A computer can read and memorize thousands of books letter-perfect. Does that mean the computer is more intelligent than a person? No, it means that in the specific task of memorizing books, a computer is much more capable than a person.
>
> …
>
> I define the term *mini-singularity* to be a cognitive problem-solving or task-accomplishing situation in which a computer or robot can far out perform a human.

Think of a hand-held scientific calculator as a technological mini-singularity. For a much more sophisticated example, think of a search engine such as Google as being a technological mini-singularity. Each has a type of "intellectual" capability that is quite different from that of a human brain, and each has produced major changes in education.

Three Brains Are Better Than One

The following paragraphs are quoted from the first part of Moursund (2015b):

> In the early days of electronic digital computers, such machines were often referred to as "brains" or "electronic brains." A much more accurate description for such early computers is "automated calculating machines." These early computers were designed to rapidly and accurately carry out a specified sequence of arithmetic calculations. Initially, one such computer could do the work of more than a hundred people equipped with the best calculators of that time.
>
> Since mass production of computers first began in the very early 1950s, they have become about 10 billion times as cost effective as they were initially. Large numbers of computer programs have been written that solve a wide range of math and non-math

problems. Artificial Intelligence (Machine Intelligence) has become a productive component of the field of Computer and Information Science.

…

[On August 4, 2009, I gave a conference presentation] on the role of three types of brains in representing and solving math problems:

- Human brain (a "meat" brain).
- Paper & pencil (reading and writing) brain. The external storage media is static, while the thinking is done by the meat brain.
- Information and Communication Technology (ICT) brain. The external storage can be static or dynamic. It can do things on its own, and it can interact with the human brain. Computers have a certain level/type of intelligence and this is steadily increasing.

Currently, we date the beginnings of anthropologically modern humans to about 200,000 years ago. It was only about 11,000 years ago that humans developed agriculture, and only about 5,300 years ago when they developed reading and writing. It took more than 5,000 years from the invention of reading and writing until it became clear that all children should learn to read and write. Now, this aspect of language arts is a requirement in elementary schools throughout the world.

Contrast this 5,000-year time period with how rapidly computer technology has developed and how rapidly people have learned to use it effectively. Observe an adolescent making full use of the features of a modern Smartphone and you will see how progress in deep and widespread use of this technology has moved about a hundred times as fast as the widespread adoption of reading and writing.

Since computers have become commonplace, our educational system has struggled with what students should be learning about Information and Communication Technology (ICT) and the roles of ICT in everyday schooling. We have accepted that students should be expected to use their reading and writing skills when they are being tested. We have accepted (and, indeed, begun to require) that students use ICT in all of their schooling except tests. Can allowing and requiring use of ICT on tests be too long in coming?

Brain-Computer Interface

For most students, initial instruction in reading begins well before they begin kindergarten. Parents and guardians routinely hold children on their laps and read picture books to them. Students are still working on their reading and writing skills when they get to college. Many of them find it is quite difficult to meet “contemporary standards.”

When electronic digital computers first began to be developed near the end of the 1930s and on into the late 1940s, the human-computer interface consisted of rewiring the computer to handle a specific problem. That is, computer programming was a rewiring process.

Then the idea of having a computer program produced outside of a computer and inserted into the computer’s memory circumvented the rewiring process. This idea of a stored program was a major breakthrough and a much better approach to the interface problem. People could learn to program in a machine language without having to understand details of wiring or

electronics. A machine could be switched quickly from working on one problem to working on a different problem. Still, it took quite a long time—perhaps a year—to become a skilled programmer.

Then came "higher level" programming languages such as FORTRAN and COBOL. FORTRAN was developed for scientists during the period from 1953 to 1957 and required about 20 person-years of effort on the part of quite smart designers and programmers. The resulting human-computer interface allowed a person skilled in high school mathematics to begin writing quite useful programs after two weeks or so of instruction. Very roughly speaking, this advance in the human-computer interface speeded up the learning process and the productivity of a programmer by a factor of perhaps ten to twenty.

As it became clear that precollege students could learn to program and benefit through this experience, programming languages such as BASIC and Logo were developed for students and quickly became popular in precollege education.

Stephen Hawking

Over the years, there have continued to be very important advances in human-computer interfaces. Stephen Hawking is a well-known physicist who contracted amyotrophic laterals sclerosis (ALS) in 1963 and has had to cope with declining physical capabilities ever since.

After Stephen Hawking lost his ability to speak in 1985, he initially communicated using a spelling card, patiently indicating letters and forming words with a lift of his eyebrows. Eventually, computer technology began to be used to allow him to produce voice and to use a word processor. Joao Medeiros' article, Giving Steven Hawking a Voice, provides an excellent story of advances in computer technology that have helped Hawking (Medeiros, January, 2015).

In 2013, Hawking was provided with a new, state-of-the art computer interface. The following quoted material from Medeiros captures Hawking's challenge of learning to make use of the new interface and the capabilities it provides.

> It was many more months before the Intel team came up with a version that pleased Hawking. For instance, Hawking now uses an adaptive word predictor from London startup SwiftKey which allows him to select a word after typing a letter, whereas Hawking's previous system required him to navigate to the bottom of his user interface and select a word from a list. "His word-prediction system was very old," says Nachman. "The new system is much faster and efficient, but we had to train Stephen to use it. In the beginning he was complaining about it, and only later I realized why: he already knew which words his previous systems would predict. He was used to predicting his own word predictor." Intel worked with SwiftKey, incorporating many of Hawkins's documents into the system, so that, in some cases, he no longer needs to type a character before the predictor guesses the word based on context. "The phrase 'the black hole' doesn't require any typing," says Nachman. "Selecting 'the' automatically predicts 'black'. Selecting 'black' automatically predicts 'hole'."
>
> The new version of Hawking's user interface (now called ACAT, after Assistive Contextually Aware Toolkit) includes contextual menus that provide Hawking with various shortcuts to speak, search or email; and a new lecture manager, which gives him control over the timing of his delivery during talks.

There are many aspects of using computers that have been made so intuitive that little or no formal instruction is needed to learn to use them. Children are intrinsically motivated to learn from each other and by trial and error. Many adult learners have lost this valuable trait.

Machine Learning

Quoting from a Stanford machine learning MOOC:

> Machine learning is the science of getting computers to act without being explicitly programmed. In the past decade, machine learning has given us self-driving cars, practical speech recognition, effective web search, and a vastly improved understanding of the human genome. Machine learning is so pervasive today that you probably use it dozens of times a day without knowing it.

Quoting from Alex Woodie's article, How Machine Learning Is Eating the Software World (Woodie,5/18/2015):

> In today's big data world, the focus is all about building "smart applications." The intelligence in those apps, more often than not, doesn't come from adding programmatic responses to the code–**it comes from allowing the software itself to recognize what's happening in the real world, how it's different from what happened yesterday, and adjust its response accordingly.**
>
> Armed with every-increasing volumes of data and sophisticated machine learning modeling environments, we're able to discern patterns that were never detectable before. [Bold added for emphasis.]

A computer program can be thought of as a type of knowledge (a set of instructions) that can be inserted into a computer memory. That is, programming can be thought of as a process of teaching a computer how to solve a particular type of problem or accomplish a particular type of task.

However, it became clear in the early days of computer programming that computers were not really gaining in intelligence (acquiring artificial intelligence) through the human development of large libraries of computer programs.

While it was possible to write a program that would never lose when playing a simple game such as Tic-Tac-Toe with a human, a much greater challenge was to write a program that could play checkers or chess quite well. The number of possible moves in such games is so large that a rote memory approach—writing a program that has memorized the best move to make in every possible situation—will not work. The number of possible moves is so large that this is an impossible task.

So, some programmers set themselves the challenge of developing computer programs that could play checkers or chess using a combination of rote memory of "good moves" and by learning through trial and error (aided by humans). In essence, computer programs were developed that could play against other computer programs and learn in the process. Human trial and error learning tends to be very slow, because it takes a long time to develop a feasible trial, implement it, and figure out how well it works. A computer can be a million times as fast. **In 1997 an IBM computer named Big Blue won a 6-game chess match against the world's leading human chess player.**

Years and years of progress in machine learning have led to the development of computer software that is quite good at learning to solve a variety of problems of interest to humans. Douglass Hofstadter has been working for years on exploring and developing computer programs that actually have intelligence—that "really think" (Somers, November, 2013). Quoting from the article:

> "Cognition is recognition," he [Hofstadter] likes to say. He describes "seeing as" as the essential cognitive act: you see some lines as "an A," you see a hunk of wood as "a table," you see a meeting as "an emperor-has-no-clothes situation" and a friend's pouting as "sour grapes" and a young man's style as "hipsterish" and on and on ceaselessly throughout your day. That's what it means to understand. But how does understanding work? For three decades, Hofstadter and his students have been trying to find out, trying to build "computer models of the fundamental mechanisms of thought."
>
> …
>
> Of course in Hofstadter's telling, the story goes like this: when everybody else in AI started building products, he and his team, as his friend, the philosopher Daniel Dennett, wrote, "patiently, systematically, brilliantly," way out of the light of day, chipped away at the real problem. "Very few people are interested in how human intelligence works," Hofstadter says. "That's what we're interested in—what is thinking?—and we don't lose track of that question."

Building Computer Models of the Human Brain

This Three Brains chapter of Brain Science began with a discussion of the singularity (when computers become more capable—perhaps more intelligent—than humans). There are two general approaches to such a challenge in the discipline of Computer and Information Science. One is to develop computer programs that solve problems that humans consider to be challenging or quite difficult. The other is to develop a computer brain that is modeled on a human brain and functions like it. This section focuses on developing computer models of the human brain that can think and in some sense function like a human brain.

Modeling the human brain is certainly one of the grand challenges in the field of artificial intelligence (Crick, 1979). Some day—perhaps quite a few decades from now—humans may succeed in building a computer that has the cognitive capabilities of a human brain.

You might wonder why such forecasts are for quite far into the future, and accompanied by "we may succeed." After all, we have built a computer system that can play chess better than a world chess champion, and we have built a computer system that can play the TV game show *Jeopardy* better that human champions in the game. See http://i-a-e.org/iae-blog/entry/the-future-of-ibm-s-watson-computer-system.html and http://i-a-e.org/iae-blog/entry/comparing-human-and-computer-brains.html.

These milestone successes depended on using some of the fastest computers of their time, devoting a huge number of human hours to analyzing the specific problems to be solved, developing programs to solve these problems, and limiting the quite narrow range of the problems. These successes were not based on computer programs that have human-like understanding.

There are many other intelligence-related areas in which significant progress is being made. Language translation and voice-to-text input are excellent examples. These problems have been

solved at a useful/usable level, but the computer systems have no understanding of the meaning of the text they are processing. See http://translate.google.com/about/.

The article, IBM Teams With Leading Universities to Advance Research in Cognitive Systems (IBM, 10/2/2013), discusses some current work being done by one of the major brain modeling projects. Clearly this project represents a number of different coming mini-singularities in medicine, business, education, and other fields. Here are several quotes from the article:

> IBM (NYSE: IBM) today announced a collaborative research initiative with four leading universities to advance the development and deployment of cognitive computing systems–systems like IBM Watson that can learn, reason and help human experts make complex decisions involving extraordinary volumes of fast-moving data.
>
> "IBM has demonstrated with Watson that cognitive computing is real and delivering value today," said Zachary Lemnios, vice president of strategy for IBM Research. "It is already starting to transform the ways clients navigate big data and is creating new insights in healthcare, how research can be conducted and how companies can support their customers. But much additional research is needed to identify the systems, architectures and process technologies to support a new computing model that enables systems and people to work together across any domain of expertise."
>
> ...
>
> "I believe that cognitive systems technologies will make it possible to connect people and computers in new ways so that—collectively—they can act more intelligently than any person, group, or computer has ever done before," said Thomas Malone, Director of the MIT Center for Collective Intelligence and the Patrick J. McGovern Professor of Management, MIT Sloan School of Management. "I am excited to be working with IBM and these other universities to understand better how to harness these new forms of collective intelligence."

Ray Kurzweil has long been a leader in brain modeling. See http://iae-pedia.org/Ray_Kurzweil. The following quote is from an article by Kurzweil (7/28/2010) that indicates where we were in 2010:

> The Proceedings of the National Academy of Sciences (PNAS) published Tuesday a landmark paper entitled “Network architecture of the long-distance pathways in the macaque brain” (an open-access paper) by Dharmendra S. Modha (IBM Almaden) and Raghavendra Singh (IBM Research-India) with major implications for reverse-engineering the brain and developing a network of cognitive-computing chips.
>
> “We have successfully uncovered and mapped the most comprehensive long-distance network of the Macaque monkey brain, which is essential for understanding the brain’s behavior, complexity, dynamics and computation,” Dr. Modha says. “We can now gain unprecedented insight into how information travels and is processed across the brain."
>
> “We have collated a comprehensive, consistent, concise, coherent, and colossal network spanning the entire brain and grounded in anatomical tracing studies that is a stepping stone to both fundamental and applied research in neuroscience and cognitive computing.”

A more recent article, Kurzweil: The Human Brain on IT, provides background about Kurzweil and some of his forecasts for the future of brain modeling (Tucci, September, 2013). Quoting from this article:

> "Change is the new constant" is a saying you hear a lot at technology conferences. "But change is not constant," said inventor and futurologist Ray Kurzweil.
>
> …
>
> Consider our first information technology, he said—spoken language. A byproduct of our large brains, human language took hundreds of thousands of years to evolve. Written language, the next big advance in information technology, took tens of thousands of years to develop. The printing press took 400 years to become commonplace. The telephone, 50 years. The mass uptake of the cell phone by Western populations took seven years, according to his calculations, social networks even less time.
>
> The big change to come? Look within. Our neocortex—the convoluted rind of the brain responsible for this sustained technology evolution—has already been extended by our computer-enabled access to information. In the next few decades, said Kurzweil, author of *How to Create a Mind,* our brains will essentially grow by harnessing the power of information technology. Why, if we can hang on long enough, information technology will extend not only our brains but our lives, perhaps forever.

Neuroprosthetics

My 5/22/2015 Google search of *neuroprosthetics* produced about 131,000 results. Quoting from the Wikipedia:

> Neuroprosthetics (also called neural prosthetics) is a discipline related to neuroscience and biomedical engineering concerned with developing neural prostheses. They are sometimes contrasted with a brain-computer interface, which connects the brain to a computer rather than a device meant to replace missing biological functionality.

The difference between human-machine and human-prosthetics interface is subtle. Brain control of a word processing machine is human-machine interface. Brain control of an artificial hand is neuroprosthetics. Neuroprosthetics has a long history and is making rapid progress. Quoting from Neuroprosthetics (Leuthardt, Roland, & Ray, 11/1/2014):

> Neuroprosthetic research began long before it solidified as an organized academic field of study. In 1973, University of California, Los Angeles, computer scientist Jacques Vidal observed modulations of signals in the electroencephalogram of a patient and wrote in Annual Review of Biophysics and Bioengineering: "Can these observable electrical brain signals be put to work as carriers of information in man-computer communication or for the purpose of controlling such external apparatus as prosthetic devices or spaceships?" While we don't yet have mind-controlled spaceships, neural control of a prosthetic device for medical applications is now becoming commonplace in labs around the world.
>
> …
>
> In its simplest form, a neuroprosthetic is a device that supplants or supplements the input and/or output of the nervous system. For decades, researchers have eyed neuroprosthetics as ways to bypass neural deficits caused by disease, or even to augment existing function for improved performance. Today, several different types of surgical brain implants are

> being tested for their ability to restore some level of function in patients with severe sensory or motor disabilities. In a very different vein, a company called Foc.us recently started selling simple, noninvasive brain stimulators to improve normal people's attention while gaming. And perhaps the most visible recent demonstration of the power of neuroprosthetics was a spinal cord–injured patient using a brain-controlled exoskeleton to kick off the 2014 World Cup in Brazil. In short, tinkering with the brain has begun in earnest.
>
> …
>
> But information transfer via neuroprostheses is not a one-way street; some systems are able to convert environmental stimuli into perceptions by capturing an external input and translating it into an appropriate stimulus delivered directly to the nervous system. In this light, researchers have developed cochlear implants and functional retinal prostheses. (See http://www.the-scientist.com/?articles.view/articleNo/41052/title/The-Bionic-Eye/.)

Deep Brain Stimulation

The history of performing operations on the brain and/or trying to stimulate the brain is quite long. Quoting from Andres Lozano's article, Tuning the Brain, (Lozono, 10/28/2015):

> The world's first neurosurgeries took place about 7,000 years ago in South America with the boring of holes into hapless patients' skulls, a process known as trephination. Practitioners of the day believed the source of neurologic and psychiatric disease to be evil spirits inhabiting the brain, and the way to treat such disorders, they reasoned, was to make holes in the skull and let the evil spirits escape. The procedure was surprisingly common, with as many as 1 percent of skulls at some archaeological sites having these holes.

Over the past 7,000 years we have moved past the "evil spirits" explanations, and have developed a wide variety of approaches to deal with brain pains and other brain disorders. Although we have come a long way, we still have a very long way to go. Deep brain electrical stimulation (DBS) is currently one of the new approaches that is proving successful. Quoting again from the Lozano article:

> Today, neurosurgeons are still drilling into the brains of patients suffering from neurologic and psychiatric disorders, but rather than letting evil spirits escape, doctors are putting things in—inserting electrical probes to tame rogue neurons or to stimulate brain regions that are underperforming. This procedure, known as deep-brain stimulation (DBS), was first tried for the treatment of pain in the 1960s, and has since been attempted in patients with numerous other neurologic disorders. DBS is currently approved in the U.S. or Europe for the treatment of essential tremor, Parkinson's disease, dystonia (a motor disorder that causes extreme twisting and repetitive motions), epilepsy, and obsessive-compulsive disorder (OCD). The therapy is currently in clinical trials for depression, Alzheimer's disease, addiction, and more.

Quoting from the article, Deep Brain Stimulation (Mayo Clinic Staff, 2015):

> Deep brain stimulation involves implanting electrodes within certain areas of your brain. These electrodes produce electrical impulses that regulate abnormal impulses. Or, the electrical impulses can affect certain cells and chemicals within the brain. The amount of stimulation in deep brain stimulation is controlled by a pacemaker-like device placed

> under the skin in your upper chest. A wire that travels under your skin connects this device to the electrodes in your brain.
>
> Deep brain stimulation is used to treat a number of neurological conditions, such as:
>
> - Essential tremor
> - Parkinson's disease
> - Dystonia (a neuromuscular disorder)
>
> Deep brain stimulation is also being studied as a treatment for epilepsy, cluster headaches, Tourette syndrome, chronic pain, and major depression. Many candidates for deep brain stimulation are participants in clinical trials.

Finally, as noted in the Neurogenesis: Growing New Neurons section of Chapter 3, DBS is being used to help the hippocampus to grow new neurons.

You and Your Students

As your students make a place for themselves in the adult world, they will routinely encounter artificially intelligent computer systems that are steadily growing in capability.

As a teacher at any grade level and in any discipline, you are faced by the challenge of deciding what you want your students to know about the artificial intelligence of computers, and how computers gain that intelligence. You will want them to understand similarities and differences between human intelligence and computer intelligence. You will want to help them carve out a niche where they can achieve a high and satisfying quality of life.

Here is an activity you can use to introduce your students to the general idea of technological singularity and to specific examples of mini-singularities. You and your students can work together to discover and explore mini-singularities that are relevant to the content, instruction, and evaluation for the course material they are learning from you. See Moursund (2015a) to learn more about self-assessment and to access a number of self-assessment instruments available free on the Web.

If your students have reached a level at which they can make effective use of self-assessment instruments, use such materials as an example of a mini-singularity that is developing in the assessment component of education. You might try the following assignment.

Ask your students to select a topic or area that is personally interesting to them. If you think it is necessary, then add the requirement that the topic or area must be in some way related to the course you are teaching. But be aware that this requirement may damage intrinsic motivation on the part of your students to take the assignment seriously!

> Select a topic or area that interests you. Decide on ways in which you can measure your own current knowledge and skills in this area. Develop a plan of action to improve your knowledge and skills, and carry your plan out for a “reasonable” period of time. Then assess yourself to see what progress you have made. Finally, produce a written or oral report on the overall process you carried out and the progress you made.

Note that developing skill in carrying out such an assignment—and gradually incorporating use of this skill into one’s overall life routines—can be thought of as developing a personal mini-singularity.

References and Resources for Chapter 4

Bull, B. (11/17/2013). 10 uses of MOOCs for high school students. *Etale–Digital Age Learning.* Retrieved 5/16/2015 from http://etale.org/main/2013/11/17/10-uses-of-moocs-for-high-school-students/.

It is interesting that college-level MOOCS are being used by many precollege students. In addition, MOOCS are being developed for precollege students.

Crick, F. (1979). Thinking about the brain. *Scientific American.* The article is pages 131-137 in the *Scientific American* book, *The brain*. Retrieved 5/17/2015 from http://www.federaljack.com/ebooks/Consciousness%20Books%20Collection/Scientific%20American%20-%20The%20Brain%20%281979%29.pdf.

This 1979 book is a "golden oldie" of articles about the (then) state of the art of brain science. Quoting from Crick's article:

> …there are some human abilities that appear to me to defeat our present understanding.… This suggests that our entire way of thinking about such problems may be incorrect. In the forefront of the problems I would put perception, although here others might substitute conception, imagination, volition, or emotion.

Eagleman, D. (March, 2015). Can we create new senses for humans? (Video, 20:34.) *TED Talks.* Retrieved 4/27/2015 from https://www.ted.com/talks/david_eagleman_can_we_create_new_senses_for_humans?language=en. Quoting from the website:

> As humans, we can perceive less than a ten-trillionth of all light waves. "Our experience of reality," says neuroscientist David Eagleman, "is constrained by our biology." He wants to change that. His research into our brain processes has led him to create new interfaces — such as a sensory vest — to take in previously unseen information about the world around us.

IBM teams with leading universities to advance research in cognitive systems (10/2/2013). Retrieved 10/2/2013 from http://www.prnewswire.com/news-releases/226080091.html.

IBM is implementing the idea of loaning a Watson computer to a leading research department in a leading university, and then drawing on the results they produce in using the computer system.

Kish, D. (March, 2015). How I use sonar to navigate the world. (Video, 13:03.) *TED Talks.* Retrieved 4/27/2015 from http://www.ted.com/talks/daniel_kish_how_i_use_sonar_to_navigate_the_world. Quoting from the website:

> Daniel Kish has been blind since he was 13 months old, but has learned to "see" using a form of echolocation. He clicks his tongue and sends out flashes of sound that bounce off surfaces in the environment and return to him, helping him to construct an understanding of the space around him.

Kurzweil, R. (7/28/2010). IBM scientists create most comprehensive map of the brain's network. Retrieved 8/2/2010 from http://www.kurzweilai.net/ibm-scientists-create-most-comprehensive-map-of-the-brains-network. Quoting from the article:

Leuthardt, E. (11/1/2014). Mind, powered. (Video, 5:01.) *The Scientist*. Retrieved 5/17/2015 from http://www.the-scientist.com//?articles.view/articleNo/41367/title/Mind--Powered/.

In this short video, neuroscientist Eric Leuthardt shows examples of mind-controlled human-computer interfaces.

Leuthardt, E., Roland, J., & Ray, W. (11/1/2014). Neuroprosthetics. *The Scientist.* Retrieved 5/17/2015 from http://www.the-scientist.com/?articles.view/articleNo/41324/title/Neuroprosthetics/.

Lozana, A. (10/28/2015). Tuning the brain. *New Scientist.* Retrieved 5/21/2015 from http://www.the-scientist.com/?articles.view/articleNo/38047/title/Tuning-the-Brain/. Quoting from the article:

> Deep-brain stimulation is allowing neurosurgeons to adjust the neural activity in specific brain regions to treat thousands of patients with myriad neurological disorders.

Mayo Clinic Staff (2015). Deep brain stimulation. *Mayo Clinic.* Retrieved 5/21/2015 from http://www.mayoclinic.org/tests-procedures/deep-brain-stimulation/basics/definition/prc-20019122. Quoting from the website:

> Mayo Clinic in Minnesota has been recognized as the best Neurology & Neurosurgery hospital in the nation for 2014-2015 by *U.S. News & World Report.*

Medeiros, J. (January, 2015). Giving Steven Hawking a voice. Originally published in *Wire Magazine*. Retrieved 5/17/2015 from http://www.wired.co.uk/magazine/archive/2015/01/features/giving-hawking-a-voice. Quoting from the article:

> Stephen Hawking first met Gordon Moore, the cofounder of Intel, at a conference in 1997. Moore noticed that Hawking's computer, which he used to communicate, had an AMD processor and asked him if he preferred instead a "real computer" with an Intel micro-processor. Intel has been providing Hawking with customised PCs and technical support since then, replacing his computer every two years.

Moursund, D. (2015a). Self assessment. *IAE-pedia.* Retrieved 5/15/2015 from http://iae-pedia.org/Self_Assessment.

One of the most important goals in education is to help students to gain steadily increasing knowledge and skills in taking responsibility for their own learning and for the effective and responsible use of their learning.

Moursund, D. (2015b). Two brains are better than one. *IAE-pedia.* Retrieved 5/17/2015 from http://iae-pedia.org/Two_Brains_Are_Better_Than_One.

This extensive *IAE-pedia* entry includes background information in areas such as computational thinking, expertise, information overload, and problem solving.

Moursund, D. (5/16/2015). Technology-based mini-singularities. *IAE Blog.* Retrieved 5/17/2015 from http://i-a-e.org/iae-blog/entry/technology-based-mini-singularities.html. Quoting from the article:

> We also now have Massive Open Online Courses (MOOCs) that can simultaneously teach a class of a hundred thousand or more students. As MOOCs become more available

and more like Highly Interactive Intelligent Computer-assisted Learning (HIICAL) systems, they will constitute a mini-singularity of instructional delivery.

Moursund, D. (3/5/2015). Education for the coming technological singularity. *IAE Blog*. Retrieved 5/15/2015 from http://i-a-e.org/iae-blog/entry/education-for-the-coming-technological-singularity.html. Quoting from the article:

> Right now the rate of technological change is both large and rapidly increasing. We have artificially intelligent computer systems that are more capable than humans in certain limited areas, and we have artificially intelligent robots that are taking over many jobs previously performed by human workers.

Moursund, D. (2/25/2015). The coming educational singularity. *IAE Blog*. Retrieved 5/15/2015 from http://i-a-e.org/iae-blog/entry/the-coming-technological-singularity.html. Quoting from the article:

> The first use of the term *singularity* in this context was by mathematician John von Neumann. In 1958, regarding a summary of a conversation with von Neumann, Stanislaw Ulam [reported that von Neumann] described "ever accelerating progress of technology and changes in the mode of human life, which gives the appearance of approaching some essential singularity in the history of the race beyond which human affairs, as we know them, could not continue."

Moursund, D. (2005). *Introduction to information and communication technology in education.* Eugene, OR: Information Age Education. Available for free downloads: Microsoft Word file from http://i-a-e.org/downloads/free-ebooks-by-dave-moursund/18-introduction-to-information-and-communication-technology-in-education-1.html. PDF file from http://i-a-e.org/downloads/free-ebooks-by-dave-moursund/17-introduction-to-information-and-communication-technology-in-education.html. This short book has three goals:

1. To help to increase the reader's expertise as a teacher.
2. To help to increase the reader's knowledge and understanding of various roles of ICT in curriculum content, instruction, and assessment.
3. To help to increase the reader's higher-order, critical thinking, problem-solving knowledge and skills.

Moursund, D. (September, 2002). Getting to the second order: Moving beyond amplification uses of information and communications technology in education. *Learning and Leading with Technology*. Retrieved 5/15/2015 from http://pages.uoregon.edu/moursund/dave/Article&Presentations/second_order.htm. Quoting from the article (written 13 years ago):

> My prediction is that the next three decades will see Information and Communication Technology being a disruptive force in education. Large changes will occur, and many of our schools and school systems that attempt to follow the “traditional” path of the past decades will not prosper.

National Writing Project (5/3/2011). Writing and the brain: Neuroscience shows the pathways to learning. Retrieved 6/6/2015 from http://www.nwp.org/cs/public/print/resource/3555. Quoting from the document:

Judy Willis, a neurologist and teacher-consultant with the South Coast Writing Project, explains how the teaching of writing is important for learning based on neuroimaging and brain mapping.

Somers, J. (November, 2013). The man who would teach machines to think. *The Atlantic.* Retrieved 5/18/2015 from http://www.theatlantic.com/magazine/archive/2013/11/the-man-who-would-teach-machines-to-think/309529/. Quoting from the document:

> Douglas Hofstadter, the Pulitzer Prize–winning author of Gödel, Escher, Bach, thinks we've lost sight of what artificial intelligence really means. His stubborn quest [is] to replicate the human mind.

Tucci, L. (September, 2013). Kurzweil: The human brain on IT. *Pro+*. Retrieved 5/20/2015from http://searchcio.techtarget.com/opinion/Kurzweil-The-human-brain-on-IT. Quoting from the article:

> [Kurzweil] is the inventor of the first charge-coupled device, or CCD, flatbed scanner; the first omni-font character recognition technology; the first print-speech reading machine for the blind; the first text-to-speech synthesizer; and the first music synthesizer capable of recreating the sounds of orchestral instruments. Recently he was named director of engineering at Google, where he is working on understanding natural language.

Woodie, A. (5/18/2015). How machine learning is eating the software world. *Datanimi.* Retrieved 5/18/2015 from http://www.datanami.com/2015/05/18/how-machine-learning-is-eating-the-software-world/. Quoting from the article:

> The big cloud players, Amazon, Microsoft Azure, and Google Cloud, have all launched cloud-based machine learning systems that allow developers to call machine learning tasks through an Application Program Interface (API).

Chapter 5. Intelligence

> "Did you mean to say that one man may acquire a thing easily, another with difficulty; a little learning will lead the one to discover a great deal; whereas the other, after much study and application, no sooner learns than he forgets?" (Plato; Classical Greek philosopher, mathematician, writer of philosophical dialogues, and founder of the Academy in Athens, the first institution of higher learning in the western world; 428/427 BC-348/347 BC.)

Intelligence (Human Intelligence Quotient)

There are many definitions of intelligence. One definition is "A score on an IQ test." I consider that to be a rather lame definition.

My personal definition is that intelligence is a combination of the creative ability to:

1. Learn. This includes all kinds of informal and formal learning via any combination of experience, education, and training.

2. Recognize and pose problems. This includes recognizing ill-defined problem situations and transforming them into more clearly defined problems.

3. Solve problems. This includes solving problems, accomplishing tasks, fashioning products, and carrying out complex projects.

This definition of intelligence is a very optimistic one. It says that each of us can become more intelligent. We can become more intelligent through study and practice, through life experiences (including growing up), through access to appropriate tools, and through learning to make effective use of these tools.

People routinely use the term IQ when talking about intelligence. This is a raw score on a test that is normed by age. Suppose that you (an adult) have an IQ of 110, and you meet a six-year-old child with an IQ of 110. How do you reconcile the huge differences between your cognitive capabilities and that of the child? The answer lies in who gets compared to whom. The child of age six is compared to other children of age six, and is somewhat above average among six year olds. This way of defining/determining IQ means that one's "raw score" on an IQ test has to increase year after year until adulthood, in order to produce an IQ score that is the same each year.

The quote from Plato at the beginning of this chapter provides evidence that people have been interested in the topic of intelligence for well over 2,000 years. In more modern times, Charles Spearman argued in a 1904 research paper that there is a general intelligence factor (named "g"), and his theory still is strongly supported. Note that a capital "G" is sometimes used instead of a lower case "g." Quoting from the Spearman paper:

> When asked what G is, one has to distinguish between the meanings of terms and the facts about things. G means a particular quantity derived from statistical operations.

> Under certain conditions the score of a person at a mental test can be divided into two factors, one of which is always the same in all tests, whereas the other varies from one test to another; the former is called the general factor or G, while the other is called the specific factor. This then is what the G term means, a score-factor and nothing more.
>
> …
>
> G is in the normal course of events determined innately; a person can no more be trained to have it in higher degree than he can be trained to be taller.

Remember, that paper was written more than a hundred years ago. At approximately the same time Alfred Binet, a French psychologist, began working on the development of an IQ test. Quoting from the Wikipedia:

> In 1904 a French professional group for child psychology, La Société Libre pour l'Etude Psychologique de l'Enfant, was called upon by the French government to appoint a commission on the education of retarded children. The commission was asked to create a mechanism for identifying students in need of alternative education. Binet, being an active member of this group, found the impetus for the development of his mental scale.
>
> Binet and Simon, in creating what historically is known as the Binet-Simon Scale, comprised a variety of tasks they thought were representative of typical children's abilities at various ages. This task-selection process was based on their many years of observing children in natural settings. They then tested their measurement on a sample of fifty children, ten children per five age groups. The children selected for their study were identified by their school teachers as being average for their age. The purpose of this scale of normal functioning, which would later be revised twice using more stringent standards, was to compare children's mental abilities relative to those of their normal peers to compare children's mental abilities relative to those of their normal peers.

Notice the modest size and the severe limitations of this initial study. Research in human intelligence has come a long way since then!

Howard Gardner, David Perkins, and Robert Sternberg are current researchers who have written widely read books about intelligence.

Howard Gardner

Of these three, Howard Gardner is probably best known by K-12 educators. His 1983 book, *Frames of Mind: The Theory of Multiple Intelligences,* proposed that humans have at least seven different types of intelligences. This resonated with me, since I seem to have much more natural talent in some areas than in others. By the time I started elementary school, it was clear that I had much more "natural" talent in math than in music.

Here is a table of Gardner's current list of intelligences retrieved from http://web.cortland.edu/andersmd/learning/MI%20Theory.htm.

	Intelligence	**Skills and Career Preferences**
1.	Verbal-Linguistic Intelligence Well-developed verbal skills and sensitivity to the sounds, meanings	Skills - Listening, speaking, writing, teaching. Careers - Poet, journalist, writer, teacher, lawyer, politician, translator

	and rhythms of words	
2.	Mathematical-Logical Intelligence Ability to think conceptually and abstractly, and capacity to discern logical or numerical patterns	Skills - Problem solving (logical & math), performing experiments Careers - Scientists, engineers, accountants, mathematicians
3.	Musical Intelligence Ability to produce and appreciate rhythm, pitch and timber	Skills - Singing, playing instruments, composing music Careers - Musician, disc jockey, singer, composer
4.	Visual-Spatial Intelligence Capacity to think in images and pictures, to visualize accurately and abstractly	Skills - puzzle building, painting, constructing, fixing, designing objects Careers - Sculptor, artist, inventor, architect, mechanic, engineer
5.	Bodily-Kinesthetic Intelligence Ability to control one's body movements and to handle objects skillfully	Skills - Dancing, sports, hands on experiments, acting Careers - Athlete, PE teacher, dancer, actor, firefighter
6.	Interpersonal Intelligence Capacity to detect and respond appropriately to the moods, motivations and desires of others	Skills - Seeing from other perspectives, empathy, counseling, co-operating Careers - Counselor, salesperson, politician, business person, minister
7.	Intrapersonal Intelligence Capacity to be self-aware and in tune with inner feelings, values, beliefs and thinking processes	Skills - Recognize one's S/W, reflective, aware of inner feelings Careers - Researchers, theorists, philosophers
8.	Naturalist Intelligence Ability to recognize and categorize plants, animals and other objects in nature	Skills - Recognize one's connection to nature, apply science theory to life Careers – Scientist, naturalist, landscape architect
9.	Existential Intelligence Sensitivity and capacity to tackle deep questions about human existence, such as the meaning of life, why do we die, and how did we get here	Skills – Reflective and deep thinking, design abstract theories Careers – Scientist, philosopher, theologian

Valerie Strauss quotes Howard Gardner in her article, 'Multiple Intelligences' Are Not 'Learning Styles' (Strauss, 10/16/2013):

> The fields of psychology and education were revolutionized 30 years ago when the now world-renowned psychologist Howard Gardner published his 1983 book *Frames of Mind: The Theory of Multiple Intelligences,* which detailed a new model of human intelligence that went beyond the traditional view that there was a single kind that could be measured by standardized tests.
>
> [Quoting Howard Gardner:] It's been 30 years since I developed the notion of "multiple intelligences." I have been gratified by the interest shown in this idea and the ways it's

> been used in schools, museums, and businesses around the world. But one unanticipated consequence has driven me to distraction—and that's the tendency of many people, including persons whom I cherish, to credit me with the notion of 'learning styles' or to collapse 'multiple intelligences' with 'learning styles.' It's high time to relieve my pain and to set the record straight.
>
> First a word about "MI theory." On the basis of research in several disciplines, including the study of how human capacities are represented in the brain, I developed the idea that each of us has a number of relatively independent mental faculties, which can be termed our "multiple intelligences." The basic idea is simplicity itself. A belief in a single intelligence assumes that we have one central, all-purpose computer—and it determines how well we perform in every sector of life. In contrast, a belief in multiple intelligences assumes that we have a number of relatively autonomous computers—one that computes linguistic information, another spatial information, another musical information, another information about other people, and so on. I estimate that human beings have 7 to 10 distinct intelligences (see the 1:47 video at www.multipleintelligencesoasis.org).

Howard Gardner's theory of Multiple Intelligences has been widely accepted and used in many schools throughout the world. In recent years, Gardner has continued his research. An excellent summary of his past decade or so of work is provided in a short video, Beyond Wit & Grit: Howard Gardner's '8 for 8' (Gardner, October 8, 2014). This talk summarizes his 30 years of work on Multiple Intelligences and his more recent work on topics such as appropriate use of one's intelligence.

In brief summary, Gardner is now working on *common sense* in one's use of one's wit (intelligence) and girt (courage and resolve; strength of character; perseverance). This work is summarized in the ideas of being a good person, worker, and citizen. A website, Good Collaboration Toolkit, provides aids for educators, practitioners, students, and researchers.

David Perkins

In a 1991 article, Mindware and Metacurriculum, David Perkins discusses a three-component theory of intelligence (Perkins, 1991). Quoting from the article:

> I suggest a framework that recognizes three basic dimensions to intelligence: the neural dimension, the experiential dimension, and the reflective dimension. Rather than rivals, these three should be considered contrasting causal factors that all contribute substantially to intelligent behavior. Such a formulation dissolves a fruitless debate and sets the stage for asking what education can do to cultivate these three dimensions of intelligence.
>
> Of them all, reflective intelligence offers the best target of opportunity for education because reflective intelligence is the most learnable of the three. Research evidence suggests that the neural component of intelligence does not change very much with instruction or practice, although there are nutritional and maturational effects. Experiential intelligence in a particular area takes years to build. But better practices of mental management, strategy use, and metacognition can be cultivated in much shorter periods-not overnight, but in months rather than years, years rather than decades.

Perkins mentions metacognition—thinking about one's thinking. Students need to understand their learning processes and to do self-regulated learning. Metacognition is an important

component of self-regulation. Quoting from Linda Nilson's article, The Secret of Self-regulated Learning (Nilson, 6/16/2014):

> …self-regulated learning is the conscious planning, monitoring, evaluation, and ultimately control of one's learning in order to maximize it. It's an ordered process that experts and seasoned learners like us practice automatically. It means being mindful, intentional, reflective, introspective, self-aware, self-controlled, and self-disciplined about learning, and it leads to becoming self-directed.
>
> Another secret about self-regulated learning is its strong positive impact on student achievement. Just the cognitive facet of it, **metacognition, has an effect that's almost as large as teacher clarity, getting feedback, and spaced practice and even larger than mastery learning, cooperative learning, time on task, and computer-assisted instruction** (Hattie, 2009).
>
> [Some sample] metacognitive questions include:
>
> - What is the best way to go about this task?
> - How well are my learning strategies working? What changes should I make, if any?
> - What am I still having trouble understanding?
> - What can I recall and what should I review?
> - How does this material relate to other things I've learned or experienced? [Bold added for emphasis.]

Robert Sternberg

Robert Sternberg (1985) is well known for his triarchic model (theory) of intelligence. Quoting from the Wikipedia:

> Sternberg categorizes intelligence into three parts, which are central in his theory, the triarchic theory of intelligence:
>
> - Analytical intelligence, the ability to complete academic, problem-solving tasks, such as those used in traditional intelligence tests. These types of tasks usually present well-defined problems that have only a single correct answer.
> - Creative or synthetic intelligence, the ability to successfully deal with new and unusual situations by drawing on existing knowledge and skills. Individuals high in creative intelligence may give 'wrong' answers because they see things from a different perspective.
> - Practical intelligence, the ability to adapt to everyday life by drawing on existing knowledge and skills. Practical intelligence enables an individual to understand what needs to be done in a specific setting and then do it.

Sometimes this set of three ideas is summarized using the terms school smarts, creativity, and street smarts. People with little or no schooling can have a remarkable level of creativity and street smarts.

There is a near universal agreement among researchers that some aspects of our intellectual abilities depend heavily on our experiential histories, and some aspects depend on our genetic makeup. Thus, a person's cognitive abilities are a combination of nature and nurture. People who

study this area talk about fluid intelligence—"gF," which is biologically based—and "gC," crystallized intelligence (based on acquired knowledge). Quoting Kendra Cherry (n.d.):

- Both types of intelligence increase throughout childhood and adolescence.
- Fluid intelligence peaks in adolescence and begins to decline progressively beginning around age 30 or 40.
- Crystallized intelligence continues to grow throughout adulthood.

From a teacher's point of view, it is important to understand that a person's life experiences—which include formal and informal education—contribute to the person's crystallized intelligence. Education is very important!

Annie Murphy Paul's article, Eight Ways of Looking at Intelligence, provides a nice summary for college educators (Paul, 6/28/2013). Quoting from the article:

> The science of learning is a relatively new discipline born of an agglomeration of fields: cognitive science, psychology, philosophy, neuroscience. Its project is to apply the methods of science to human endeavors—teaching and learning—that have for centuries been mostly treated as an art.
>
> Although I am, very much, an advocate of the science of learning, I want to emphasize that—as with anything to do with our idiosyncratic and unpredictable species—there is still a lot of art involved in teaching and learning, and for that matter, in what you do as college admissions counselors. But I do think that the science of learning can offer some surprising and useful perspectives on how we guide and educate young people.

Quoting again from Paul's article, here is one of the eight intelligence-related ideas she discusses:

> Beliefs can make us smarter. Many of you have probably encountered the work of Carol Dweck, the Stanford psychologist who wrote the terrific book *Mindset.* Dweck distinguishes two types of mindsets: the fixed mindset, or the belief that ability is fixed and unchanging, and the growth mindset, or the belief that abilities can be developed through learning and practice. Click here for an excellent 2015 *Scientific American* article, The Secret to Raising Smart Kids, by Carol Dweck.] \
>
> These beliefs matter because they influence how we think about our own abilities, how we perceive the world around us, and how we act when faced with a challenge or with adversity. The psychologist David Yeager, also of Stanford, notes that our mindset effectively creates the 'psychological world' in which we live. Students' beliefs, whether they're oriented around limits or around growth, constitute one of these internal situations that either suppresses or evokes intelligence.

Other Types of Human Intelligence

This chapter is mainly about "traditional" human intelligence that is stated in terms of IQ or level of cognitive development. However, there are other types of human intelligence.

A 6/20/2015 Google search of the expression *emotional intelligence* produced more than 13 million results. Quoting from the Wikipedia:

> Emotional intelligence (EI) is the ability to recognize one's own and other people's emotions, to discriminate between different feelings and label them appropriately, and to

> use emotional information to guide thinking and behavior. There are three models of EI. The ability model, developed by Peter Salovey and John Mayer, focuses on the individual's ability to process emotional information and use it to navigate the social environment. The trait model as developed by Konstantin Vasily Petrides, "encompasses behavioral dispositions and self perceived abilities and is measured through self report". The final model, the mixed model is a combination of both ability and trait EI. It defines EI as an array of skills and characteristics that drive leadership performance, as proposed by Daniel Goleman.

Quoting from Kendra Cherry's article, What is Emotional Intelligence? (Cherry, n.d.):

> Emotional intelligence refers to the ability to perceive, control and evaluate emotions. Some researchers suggest that emotional intelligence can be learned and strengthened, while others claim it is an inborn characteristic.

Cherry's article divides emotional intelligence into four branches:

1. Perceiving emotions. "In many cases, this might involve understanding nonverbal signals such as body language and facial expressions."
2. Reasoning with emotions. "The next step involves using emotions to promote thinking and cognitive activity. Emotions help prioritize what we pay attention and react to; we respond emotionally to things that garner our attention."
3. Understanding emotions. "The emotions that we perceive can carry a wide variety of meanings. If someone is expressing angry emotions, the observer must interpret the cause of their anger and what it might mean."
4. Managing emotions. "Regulating emotions, responding appropriately and responding to the emotions of others are all important aspects of emotional management."

A 5/25/2015 Google search of the expression *social intelligence* produced nearly 72 million hits. Quoting from the Wikipedia:

> Social intelligence, according to the original definition of Edward Thorndike, is "the ability to understand and manage men and women, boys and girls, to act wisely in human relations." It is equivalent to interpersonal intelligence, one of the nine types of intelligences identified in Howard Gardner's Theory of Multiple Intelligences, and closely related to Emotional Intelligence. Some authors have restricted the definition to deal only with knowledge of social situations, perhaps more properly called social cognition.

Daniel Goldman is the author of a number of books and a frequent speaker about both Social and Emotional Intelligence. His fundamental ideas are presented in his books, *Emotional Intelligence* (1995) and *Social Intelligence* (2006). Quoting Daniel Goleman from (Goleman Website, n.d.):

> Neuroscience has discovered that our brain's very design makes it sociable, inexorably drawn into an intimate brain-to-brain linkup whenever we engage with another person. That neural bridge lets us impact the brain—and so the body—of everyone we interact with, just as they do us.

> …
>
> The resulting feelings have far-reaching consequences, in turn rippling throughout our body, sending out cascades of hormones that regulate biological systems from our heart to immune cells. Perhaps most astonishing, science now tracks connections between the most stressful relationships and the very operation of specific genes that regulate the immune system.

Goleman emphasizes both forms of intelligence in a talk he gave to Google employees (Goleman, 8/3/2007). In this talk he explores the relationship between raw intelligence (as measured by various IQ tests) and Emotional Intelligence. His audience was top-notch (and high IQ) programmers and other Google employees. He presented an overview of Social and Emotional Intelligence in terms of:

1. **Self awareness.** What am I feeling and why am I feeling this way? This is important in decision making.
2. **Managing emotions (emotional brain)**—both the ones that get in the way of doing well in one's work, and good feelings coming from being deeply engaged in a programming task doing well on the job. He noted that the ability to delay one's gratification is important,
3. **Social brain.** He presents research on parts of the human brain specifically designed for social interaction—especially, mirror neurons.

Goleman then presents research on what makes a Google employee especially successful. I believe the six ideas listed below are applicable to employees in all occupations, and should be taught to students in our schools.

1. Drive to succeed along with high internal standards for what constitutes success.
2. Impact and influence on others (leadership).
3. Conceptual thinking. Seeing what is really matters (what is really important) in the problems and tasks one faces on the job.
4. Analyzing problems and tasks using one's cognitive intelligence (IQ) to understand and attack problems.
5. Finding and taking on relevant problems and tasks without being specifically told to do so or what to do by one's supervisor(s).
6. Being self confident and able to operate independently.

Finally, Goleman notes that while items 3 and 4 related to cognitive intelligence, the other four all relate to social and emotional intelligence. For a more recent talk by Goleman, see the video, Daniel Goleman on Focus: The Secret to High Performance and Fulfillment (Goleman, 11/2/2013). While the major topic is attention, Goleman draws on a full range of brain science research.

Cognitive Development, Stage Theory, and Brain Growth Spurts

Cognitive Development and Stage Theory

While IQ scores are normed—so a person with an IQ of 100 tends to have this same IQ as he/she grows in intelligence until reaching full mental maturity—cognitive development is

measured on a scale in which a person tends to move upward through increasing mental maturity.

Jean Piaget is well known for his four-level stage theory of cognitive development. Quoting from Saul McLeod's article, Jean Piaget (McLeod, 2015):

> Piaget (1936) described his work as genetic epistemology (i.e. the origins of thinking). Genetics is the scientific study of where things come from (their origins). Epistemology is concerned with the basic categories of thinking, that is to say, the framework or structural properties of intelligence. What Piaget wanted to do was not to measure how well children could count, spell or solve problems as a way of grading their I.Q. What he was more interested in was the way in which fundamental concepts like the very idea of "number", "time" "quantity", "causality", "justice" and so on emerged.

According to Piaget, a child moves from the Sensorimotor Stage to the Pre-operational Stage to the Concrete Operational Stage to the Formal Operational Stage. More recent research has added a number of sub-stages. Quoting from Piaget's Theory of Cognitive Development (Huitt & Hummel, 2003):

1. **Sensorimotor stage** (Infancy). In this period (which has 6 stages), intelligence is demonstrated through motor activity without the use of symbols. Knowledge of the world is limited (but developing) because its based on physical interactions / experiences. Children acquire object permanence at about 7 months of age (memory). Physical development (mobility) allows the child to begin developing new intellectual abilities. Some symbollic (language) abilities are developed at the end of this stage.
2. **Pre-operational stage** (Toddler and Early Childhood). In this period (which has two substages), intelligence is demonstrated through the use of symbols, language use matures, and memory and imagination are developed, but thinking is done in a nonlogical, nonreversable manner. Egocentric thinking predominates.
3. **Concrete operational stage** (Elementary and early adolescence). In this stage (characterized by 7 types of conservation: number, length, liquid, mass, weight, area, volume), intelligence is demonstrated through logical and systematic manipulation of symbols related to concrete objects. Operational thinking develops (mental actions that are reversible). Egocentric thought diminishes.
4. **Formal operational stage** (Adolescence and adulthood). In this stage, intelligence is demonstrated through the logical use of symbols related to abstract concepts. Early in the period there is a return to egocentric thought. **Only 35% of high school graduates in industrialized countries obtain formal operations; many people do not think formally during adulthood.** [Bold added for emphasis.]

The bolded statement in (4) is particularly important. Starting at about the 11th grade in many U.S. high schools, students have the opportunity to take Advance Placement courses. Roughly, these are equivalent to freshman college courses in a college or university that maintains high standards. These courses are taught at a level that assumes students have reached or very nearly reached formal operations. Quite a few high school juniors have a cognitive development level to handle such courses. However, the great majority of students don't.

Indeed, the performance of students on college placement tests indicates that nearly three-fourths are not adequately prepared for college freshman courses in one or more of the areas of

math, reading, and English. Some combination of the quality of their high school learning in these areas and their level of cognitive development leads them to place for remedial college courses in these areas.

Brain Growth Spurts

Brain science has been a relatively hot topic in education for more than 30 years. Arguments about the relationship of brain growth spurts to teaching and learning have continued over these years. Kurt Fischer is a world-class educator and brain scientist in the Harvard Graduate School of Education. He and many others have researched relationships between the stages of cognitive development developed by Piaget and our emerging understanding of brain growth spurts. Quoting Kurt Fisher from (*PBS FRONTLINE,* January, 2002):

> New cognitive capacities emerge at 10, 15, 20, and 25 years, in which young people become capable of using abstract concepts skillfully and relating them to each other in successively more complex ways. Younger children cannot use abstractions flexibly but instead reduce them to concrete instances and memorized definitions. At 9 to 10 years children become able to construct flexible abstract concepts, such as conformity, responsibility, and the operation of multiplication; but when they try to relate two abstractions to each other, they muddle them together. At about age 15 they can build flexible relations between a pair of abstractions and thus stop muddling them so badly. At age 19 or 20 they can build complex relations among multiple abstractions, and at 25 they can connect systems of abstractions to understand principles underlying them. Each of these developments involves the capacity to build a new kind of understanding, but that capacity is evident only in areas where young people work to construct their understanding—the new abilities do not appear in all skills but only in those where the individual demonstrates optimal performance. A major challenge for neuroscientists is to understand how these emerging capacities relate to brain changes.

Quoting from Fisher (2008):

> Many brain characteristics—number of neurons and synapses, brain mass, myelination, brain activity, and so forth—change systematically as children grow up. Simultaneously children's actions, speech, concepts, problem solving, social skills, motivation, and emotions develop. All these various changes are globally correlated, but the correlations are not very informative because everything is changing in parallel. Scientists who seek to understand brain-behavior relations and educators who want to use cognitive neuroscience to improve education need ways of finding and analyzing meaningful connections between changes in brain and behavior, moving beyond the finding that characteristics go generally up (some go generally down) with age.

Critical Thinking

In any discipline of study, problem solving includes:

- Question situations: recognizing, posing, clarifying, and answering questions.
- Problem situations: recognizing, posing, clarifying, and then solving problems.
- Task situations: recognizing, posing, clarifying, and accomplishing tasks.
- Decision situations: recognizing, posing, clarifying, and then making good decisions.

- Using higher-order critical, creative, wise, and foresightful thinking to do all of the above. Often the results are shared, demonstrated, or used as a product, performance, or presentation.

The last of the five bulleted items above is quite a bit different from the first four. It helps to define the formal operations part of Piaget's 4-stage cognitive development theory. An increasing level of cognitive maturity is evidenced by an increasing ability to use higher-order critical, creative, wise, and foresightful thinking in dealing with problems.

The following is quoted from Linda B. Nilson's article, Unlocking the Mystery of Critical Thinking (Nilson, 12/1/2014):

> …critical thinking entails an interpretation or analysis, usually followed by evaluation or judgment. It requires that learners have mastered some subject matter to think about, so it can't be done in a knowledge vacuum. It is difficult and unnatural, and it takes time and effort to learn. And it involves not only cognition but also character and metacognition/self-regulated learning. This means that learners must be willing to pursue "truth" to wherever it may lie, persist through challenges, evaluate their own thinking fairly, and abandon faulty thinking for new and more valid ways of reasoning. These are intellectual "virtues" that don't come easily to people and must be cultivated.
>
> The scholars also generally agree that students learn critical thinking by answering challenging, open-ended questions that require genuine inquiry, analysis, or assessment.

Stuart Wolpert argues that our overall educational system is not doing well in its efforts to increase students' critical thinking ability. Quoting from his article, Is Technology Producing a Decline in Critical Thinking and Analysis? (Wolpert, 1/27/2009):

> As technology has played a bigger role in our lives, our skills in critical thinking and analysis have declined, while our visual skills have improved, according to research by Patricia Greenfield, UCLA distinguished professor of psychology and director of the Children's Digital Media Center, Los Angeles.
>
> Learners have changed as a result of their exposure to technology, says Greenfield, who analyzed more than 50 studies on learning and technology, including research on multi-tasking and the use of computers, the Internet and video games.
>
> …
>
> Visual intelligence has been rising globally for 50 years, Greenfield said. In 1942, people's visual performance, as measured by a visual intelligence test known as Raven's Progressive Matrices, went steadily down with age and declined substantially from age 25 to 65. By 1992, there was a much less significant age-related disparity in visual intelligence, Greenfield said. "In a 1992 study, visual IQ stayed almost flat from age 25 to 65."

IQ Has Been Increasing Over the Past Century: The Flynn Effect

Based on long-term studies of human performance on a variety of IQ tests, average human intelligence has been increasing for quite a few years. James Flynn has been a leading researcher in this area, and the increasing IQ has come to be called the Flynn Effect (Gladwell, 12/17/2007).

Flynn has been writing about the implications of his findings for almost twenty-five years. His writings consist of a series of plainly stated statistical observations, in support of deceptively modest conclusions, and the evidence in support of his original observation is now so overwhelming that the Flynn effect has moved from theory to fact.

Flynn updates and summarizes his arguments in a *TED Talks,* James Flynn: Why Our IQ Levels Are Higher than Our Grandparents (Flynn, 9/29/2013).

In brief summary, Flynn argues that:

1. The increase in IQ is due to better informal and formal education in areas of abstract ideas, abstract reasoning, and use of metaphors.
2. The so called "findings" about racial differences in IQ are not supported by the data on which these findings have been based.

Flynn's video begins with an interesting analogy of how tools have increased our physical performance over time, and similarly how education-training-thinking tools have increased our levels of cognitive performance. He argues that our brains perform much better than in the past because we are providing them with mental tools—tools we store in our brains and that our brains use in addressing problems and tasks. That is, in the nature versus nurture debate, it isn't that nature has provided us with much better brains in the past century or so. Instead, nurture has made our brains much more capable in the types of performance areas measured by IQ tests.

Many people have attempted to explain why IQs have increased. Their research suggests a combination of improved standard of living (food, health) and decrease in poisons have played major roles. Quoting from Greg Toppo's article, Study Links Children's Lead Levels, SAT Scores (Toppo, 2/3/09):

> Could a decades-long drop in the concentration of lead in children's blood help explain rising SAT scores?
>
> A Virginia economist who pored over years of national data says there's an "incredibly strong" correlation, which adds to a growing body of research on lead's harmful effects.
>
> The findings, to be published this winter in the journal *Environmental Research*, suggest that from 1953 to 2003, the fall and rise of the average SAT math and verbal score has tracked the rise and fall of blood lead levels so closely that half of the change in scores over 50 years, and possibly more, probably is the result of lead, says economist Rick Nevin.
>
> He controlled for rising numbers of students taking SAT prep courses and for rising numbers of students who speak a foreign language at home — that would depress verbal scores.
>
> Nevin estimates that lead explains 45% of the historic variation in verbal scores and 65% in math scores.

IQ Now Seems to be Declining

In the past few years, there has been growing evidence that the IQ increase has peaked and is now declining. Quoting from Bob Holmes' article, Brain Drain: Are We Evolving Stupidity? (Holmes, 8/20/2014):

> There's no question that intelligence – as measured by IQ tests, at least – has risen dramatically since the tests were first formalized a century ago. In the US, average IQ rose by 3 points per decade from 1932 to 1978, much as in Denmark. In postwar Japan, it shot up by an astonishing 7.7 points per decade, and two decades later it started climbing at a similar rate in South Korea. Everywhere psychologists have looked, they have seen the same thing.
>
> In Denmark, the most rapid rises in IQ, of about 3 points per decade, occurred from the 1950s to the 1980s. **Scores peaked in 1998 and have actually declined by 1.5 points since then. Something similar seems to be happening in a few other developed countries, too, including the UK and Australia.**
>
> …
>
> The coming decades should provide a definitive answer. If what we are seeing in countries like Denmark is merely the end of the Flynn effect, IQ scores should stabilize in developed countries. If Woodley and his colleagues are right, we should see a continuing decline.
>
> Even if we are evolving to be more stupid, it is far from clear whether we need to worry about it. Flynn thinks the problem may just take care of itself, as societal improvements such as better healthcare and more promising employment options bring down fertility rates in every stratum of society. [Bold added for emphasis.]

John Crace's article, Children Are Less Able than They Used to Be, provides evidence that average intelligence is now decreasing (Crace, 1/24/2006). Quoting from the article:

> New research funded by the Economic and Social Research Council (ESRC) and conducted by Michael Shayer, professor of applied psychology at King's College, University of London, concludes that 11- and 12-year-old children in year 7 are "now on average between two and three years behind where they were 15 years ago," in terms of cognitive and conceptual development.
>
> "It's a staggering result," admits Shayer…. "Before the project started, I rather expected to find that children had improved developmentally. This would have been in line with the Flynn effect on intelligence tests, which shows that children's IQ levels improve at such a steady rate that the norm of 100 has to be recalibrated every 15 years or so. But the figures just don't lie. We had a sample of over 10,000 children and the results have been checked, rechecked and peer reviewed."

Animal Cognition

While this chapter is about human intelligence, it may be instructive to do a little comparison with animal intelligence. How intelligent is a chimpanzee, a dog, or a rat? How about a fish or a reptile? How are their brains similar to and different from human brains? Quoting from Animal Cognition in the Wikipedia:

> Animal cognition describes the mental capacities of animals and its study. It has developed out of comparative psychology, including the study of animal conditioning and learning, but has also been strongly influenced by research in ethology, behavioral ecology, and evolutionary psychology. The alternative name cognitive ethology is

> therefore sometimes used; much of what used to be considered under the title of animal intelligence is now thought of under this heading.
>
> Research has examined animal cognition in mammals (especially primates, cetaceans, elephants, dogs, cats, horses, raccoons and rodents), birds (including parrots, corvids and pigeons), reptiles (lizards and snakes), fish and invertebrates (including cephalopods, spiders and insects).

How do you design an IQ test for an animal? Probably you have read articles that compare the "intelligence" of a young chimpanzee with that of a young human child. For an interesting discussion, see Cadell Last's article, 5 Human/Chimpanzee Differences (Last, 6/13/2013). Last quotes Charles Darwin in the article:

> [Chimpanzees] make tools, use language, understand symbols and build shelters. They also develop long-term bonds, live in highly social groups, make jokes, manipulate, deceive, empathize, and show care for other members of their group and other species. The behavioral differences have been relegated to artificial human-constructed continuums of complexity.

The same article provides a number of examples of intelligence-related activities that chimpanzees can learn to do and also discusses limits to their learning powers. Quoting again from Last:

> The desire for humans to ask questions is remarkable. And it is even more remarkable to know that after decades of linguistic training, **no chimpanzee has ever asked a question.** No other animal on the planet has ever asked a question. Only humans do this. [Bold added for emphasis.]

A number of research studies have compared the early development of human children with young chimpanzees. My Google search on 11/20/2013 of the expression *human child chimpanzee intelligence* returned about 1.25 million hits. For example, quoting from Patti Neigmond's article, Toddlers Outsmart Chimps in Some Tasks (Neigmond, 9/7/2007):

> To investigate what makes human intelligence so different from ape intelligence, the researchers designed over two dozen tests to measure different kinds of intelligence between the two species.
>
> …
>
> [Quoting the researcher anthropologist Brian Hare:] Our subjects in this study were 2-and-a-half-year-old children. Children did not perform any better than apes on many tests that measured concrete knowledge. They weren't any better than the apes at doing things like adding, counting, remembering where something was hidden.
>
> But when it came to solving more social problems, children excelled. Hare defines a "social problem" as the ability to watch somebody else and figure out what they're trying to do — and what they want you to do. In his study, certain tests looked at how adept children and apes were at understanding someone else's intention.
>
> ...

> In one test, treats were placed in a tube purposely designed to be difficult to open. After researchers demonstrated how to open it, most of the toddlers were able to imitate and open it. On the other hand, the apes did not follow suit.

You and Your Students

Although a human brain does not grow very much in physical size after age 5 or 6, it changes markedly over the next 20 to 30 years. Your students can look at their own physical size and capabilities, and compare them with their memories of their own younger years and with those of adults. Thus, they have little trouble appreciating the fact that major changes are occurring in their physical size and capabilities.

But, it is harder to observe oneself and others, and to "see" brain changes over the years. Some brain/mind changes are self-evident. A student can think about what they have learned over some past period of time, noting increases in general knowledge and basic skills. It is much harder to detect one's changes in brain/mind occurring during adolescence or other major brain spurt times.

One approach to helping students understand that major brain/mind changes are occurring is to get them to think about somewhat older and somewhat younger children they know quite well. What differences do they notice in brain/mind-related performance? For example, you may have heard a child saying to a younger brother or sister, "Grow up! Don't be such a nerd." What is the older child noticing and referring to?

Another approach is to help students notice changes in their own cognitive capabilities over time. Some teachers have their students develop portfolios of their work to help them to see how their performances change over time.

References and Resources for Chapter 5

Annenberg (2012). Neuroscience & classroom: Making connections. (42 videos, varying lengths.) *Annenberg Learner.* Retrieved 5/31/2015 from http://www.learner.org/resources/series214.html.

Designed as a video course for grades K-12 teachers, school counselors, and college teachers, the 42 videos vary in length and often are accompanied by course guide, online text, website, and other resources.

Cherry, K. (n.d.). Fluid intelligence vs. crystallized intelligence. *About Education.* Retrieved 5/23/2015 from http://psychology.about.com/od/cognitivepsychology/a/fluid-crystal.htm. Quoting from the article:

> The Cattell-Horn theory of fluid and crystallized intelligence suggests that intelligence is composed of a number of different abilities that interact and work together to produce overall individual intelligence.

Cherry, K. (n.d.). What is emotional intelligence? *About Education.* Retrieved 5/25/2015 from http://psychology.about.com/od/personalitydevelopment/a/emotionalintell.htm.

The article includes a brief history of Emotional Intelligence going back to the 1930s when Edward Thorndike described the concept of *Social Intelligence* as the ability to get along with other people.

Crace, J. (1/24/2006). Children are less able than they used to be. *The Guardian.* Retrieved 5/24/2015 from http://www.guardian.co.uk/education/2006/jan/24/schools.uk. Quoting from the article:

> To understand both the science and its implications, we need to step back 30 years, to when Shayer was part of a six-strong team of academics…engaged in research at Chelsea College on concepts in secondary science and mathematics. "We realized that no one had actually bothered to investigate how children learned maths and science, or where the difficulties lay," he says.

Fisher, K.W. (2008). Dynamic cycles of cognitive and brain development: Measuring growth in mind, brain, and education. Retrieved 5/29/2015. Note from David Moursund. I was unable to find a simple, clickable link to this document. To retrieve a PDF of this file, do a Google search on *8 Dynamic cycles of cognitive and brain development: Measuring growth in mind, brain, and education.* Then select the PDF "hit" at or near the top of this list of hits. Quoting from the document:

> Neurocognitive development should be conceived not as a ladder of successive stages but as a complex network of interactions and attractors, convergent and divergent paths, nested cycles, stabilities and instabilities, progressions and regressions, clusters of discontinuities and stable levels of performance.

Flynn, J. (9/29/2013). James Flynn: Why our IQ levels are higher than our grandparents. (Video, 18:40.) *TED Talks*. Retrieved 5/29/2015 from http://www.ted.com/talks/james_flynn_why_our_iq_levels_are_higher_than_our_grandparents.html. Quoting from the website:

> [Flynn] argues that our brains perform much better than in the past because we are providing them with mental tools—tools we store in our brains and that our brains use in addressing problems and tasks. That is, in the nature versus nurture debate, it isn't that nature has provided us with much better brains in the past century or so. Instead, nurture has made our brains much more capable in the types of performance areas measured by IQ tests.

Gardner, H. (October 8, 2014). Beyond wit & grit: Howard Gardner's '8 for 8'. (Video, 7:43.) Harvard Graduate School of Education. *YouTube*. Retrieved 6/15/2015 from https://www.youtube.com/watch?v=vnqWZdcC8AE.

> This short video presents Howard Gardner's ideas on effective use of one's wits (Multiple Intelligences) and grit (courage and resolve; strength of character; perseverance) to be a good, responsible person.

Gardner, H. (1983). *Frames of mind: The theory of multiple intelligences.* New York: Basic.

> This is Gardner's first book about multiple intelligences. It includes a summary of the research that led him to conclude that a person has seven (or perhaps more) somewhat distinct types of intelligences.

Gladwell, M. (12/17/2007). None of the above: What I.Q. doesn't tell you about race. *The New Yorker.* Retrieved 5/30/2015 from http://www.newyorker.com/arts/critics/books/2007/12/17/071217crbo_books_gladwell.

This article provides an extensive review of *What Is Intelligence?,* a new book by James Flynn that discusses the increase in IQ that has been occurring in recent decades and throughout the world. The book and the review also discuss assertions about differences of IQ of various races.

Goleman Website (n.d.). About Daniel Goleman. Retrieved 6/21/2015 from http://www.danielgoleman.info/biography/.

This website contains a broad range of information about Goleman, including books, audio, and video.

Goleman, D. (11/2/2013). Daniel Goleman on focus: The secret to high performance and fulfillment. (Video, 1:18:18.) Retrieved 6/19/2015 from https://www.youtube.com/watch?v=HTfYv3IEOqM.

Attention today is under siege—most of us face an overwhelming collection of demands on our attention. Attention between a pair or group of people is being seriously damaged by communication technology. Also discusses Flow, stress, emotion, and so on.

Goleman, D. (8/3/2007). Authors@Google: Daniel Goleman. (Video, 55:52.) Retrieved 6/19/2015 from https://youtu.be/-hoo_dIOP8k. Quoting from the website:

> Daniel Goleman discusses his book "Social Intelligence: The New Science of Human Relationships" as a part of the Authors@Google series. This event took place on August 3, 2007 at Google headquarters in Mountain View, CA.

Goleman, D. (2006). *Social Intelligence*: *The new science of human relationships.* New York: Bantam.

A synthesis of the latest findings in biology and brain science, revealing that we are "wired to connect" and the surprisingly deep impact of our relationships on every aspect of our lives.

Goleman, D. (1995). *Emotional Intelligence: Why it can matter more than IQ.* New York: Bantam. Quoting from the site:

Using numerous examples, Goleman presents five crucial skills of emotional intelligence, and shows how they determine our success in relationships, work, and our physical well-being.

Griffiths, S. (8/21/2014). Are we becoming more STUPID? IQ scores are decreasing - and some experts argue it's because humans have reached their intellectual peak. *Mail Online.* Retrieved 10/5/2014 from http://www.dailymail.co.uk/sciencetech/article-2730791/Are-STUPID-Britons-people-IQ-decline.html#ixzz3FJL5IyPx. Quoting from the article:

> A study by the University of Hartford claims the larger the global population becomes, the less intelligent we will be, dropping by around eight IQ points by the year 2110 - and other estimates are even more pessimistic.

Holmes, B. (8/20/2014). Brain drain: Are we evolving stupidity? *New Scientist*. Retrieved 5/23/2015 from http://www.newscientist.com/article/mg22329830.400-brain-drain-are-we-evolving-stupidity.html. Quoting from the article:

> We've got smarter and smarter in the 20th century, but now there are signs that IQs have begun to fall in countries such as the UK and Australia.

Huitt, W., & Hummel, J. (2003). Piaget's theory of cognitive development. *Educational Psychology Interactive*. Retrieved 5/30/2015 from http://www.edpsycinteractive.org/topics/cognition/piaget.html. Quoting from the article:

> Piaget hypothesized that infants are born with schema operating at birth that he called "reflexes." In other animals, these reflexes control behavior throughout life. However, in human beings as the infant uses these reflexes to adapt to the environment, these reflexes are quickly replaced with constructed schemata.

Last, C. (6/13/2013). 5 human/chimpanzee differences. Retrieved 5/30/2015 from http://theadvancedapes.com/5-humanchimpanzee-differences/. Quoting from the article:

> Charles Darwin was primarily interested in divergence. He wanted to know what evolutionary pressures made organisms different. In *The Descent of Man* he spent a considerable amount of time contemplating what it was that made humans unique or special. Comparisons with the "mental faculties" of apes was often used to explore this.

McLeod, S. (2015). Jean Piaget. *Simply Psychology.* Retrieved 6/19/2015 from http://www.simplypsychology.org/piaget.html. Quoting from the article:

> Piaget (1936) was the first psychologist to make a systematic study of cognitive development. His contributions include a theory of cognitive child development, detailed observational studies of cognition in children, and a series of simple but ingenious tests to reveal different cognitive abilities.

Moursund, D. (5/15/2015). Asking more useful questions about our educational system. *IAE Blog.* Retrieved 5/30/2015 from http://i-a-e.org/iae-blog/entry/asking-more-useful-questions-about-our-educational-system.html. Quoting from the article:

> A huge new study that followed 100,000 Oregon high school graduates to community college finds that 75 percent have to take non-credit remedial classes when they get there.
>
> Poor academic readiness, not students' race or income, explained why they had to take high school- or middle school-level classes when they got to community college, according to the study….

Neigmond, P. (9/7/2007). Toddlers outsmart chimps in some tasks, not all. *NPR.* Retrieved 11/20/2013 from http://www.npr.org/templates/story/story.php?storyId=14224459. Quoting from the article:

> What makes humans different from our closest primate relatives? Scientists have grappled with the question for centuries – even more so since the discovery, in the late 1980s, that humans and apes share pretty much the same genetic code.

Nilson, L.B. (12/1/2014). Unlocking the mystery of critical thinking. *Faculty Focus.* Retrieved 5/30/2015 from http://www.facultyfocus.com/articles/instructional-design/unlocking-mystery-critical-thinking/?ET=facultyfocus:e161:285126a:&st=email. Quoting from the article:

> …most faculty don't know what critical thinking is or how to teach it. Unless faculty explicitly and intentionally design their courses to build their students' critical thinking skills and receive training in how to teach them, their students do not improve their skills (Abrami et al., 2008).

Nilson, L.B. (6/16/2014). The secret of self-regulated learning. *Faculty Focus.* Retrieved 6/6/2015 from http://ww1.facultyfocus.com/eletter/profile/1/56.html.

Metacognition is one component of self-regulated learning. Quoting Nilson: "Self-regulated learning is like your own little secret. It stirs from within you, and is the voice in your head that asks you questions about your learning."

Paul, A.M. (6/28/2013). Eight ways of looking at intelligence. *The Brilliant Report.* Retrieved 3/31/2014 from http://us2.campaign-archive1.com/?u=bc04df008d4705e4e77c2eb35&id=469f021df1&e=9fa2a82024. Quoting from the article:

> Expertise can make us smarter. One very robust line of research within the science of learning is concerned with the psychology of expertise: what goes on in the mind of an expert. What researchers have found is that experts don't just know more, they know differently, in ways that allow them to think and act especially intelligently within their domain of expertise.

PBS FRONTLINE (January, 2002). How much do we really know about the brain? *PBS FRONTLINE.* Retrieved 5/31/2015 from http://www.pbs.org/wgbh/pages/frontline/shows/teenbrain/work/how.html. Quoting from the site:

> FRONTLINE asked four prominent psychologists and neuroscientists to answer some questions about the extent of our knowledge of the brain and its development -- connections between the anatomy of the brain and behavior, new directions for research, and how close we are to translating new findings into advice for parents or educators.

Perkins, D.N. (1991). Mindware and metacurriculum. In Dickison, D., ed. (1991). *Creating the future: Perspectives on educational change.* Retrieved 5/21/2015 from http://education.jhu.edu/PD/newhorizons/future/creating_the_future/index.cfm. Quoting from the website:

> [This book] provides us with a rewarding example of concepts that, more often than not, appear to be somewhat on the side of the soft and tender. When one digs more deeply, however, it becomes increasingly apparent that educational principles and practices directed to the maximization of individual talent and potential are anything but soft in regard to their actual functioning, whether one is teacher or student or both.

Sternberg, R. (1985). *Beyond IQ: A triarchic theory of human intelligence.* New York: Barnes & Noble.

This is Sternberg's seminal book presenting his triarchic theory of human intelligence.

Strauss, V. (10/16/2013). Howard Gardner: 'Multiple Intelligences' are not 'learning styles.' *The Washington Post*. Retrieved 5/22/2015 from http://www.washingtonpost.com/blogs/answer-sheet/wp/2013/10/16/howard-gardner-multiple-intelligences-are-not-learning-styles/. Quoting from the article:

> The fields of psychology and education were revolutionized 30 years ago when the now world-renowned psychologist Howard Gardner published his 1983 book Frames of Mind: The Theory of Multiple Intelligences, which detailed a new model of human intelligence

that went beyond the traditional view that there was a single kind that could be measured by standardized tests.

Toppo, Greg (2/3/09). Study links children's lead levels, SAT scores. *USA Today.* Retrieved 2/3/09 from http://www.usatoday.com/news/education/2009-02-02-lead-SAT_N.htm. Quoting from the article:

> Over 30 years, a large body of evidence has shown that lead is a potent neurotoxin, affecting IQ, impulsivity and other factors that determine academic achievement. Nevin's study is the first to tie lead to national SAT scores.

Wolpert, S. (1/27/2009). Is technology producing a decline in critical thinking and analysis? *UCLA Newsroom.* Retrieved 6/1/2015 from http://newsroom.ucla.edu/portal/ucla/is-technology-producing-a-decline-79127.aspx. Quoting from the report:

> As technology has played a bigger role in our lives, our skills in critical thinking and analysis h our visual skills have improved, according to research by Patricia Greenfield, UCLA distinguished professor of psychology and director of the Children's Digital Media Center, Los Angeles.

Chapter 6. Creativity, Curiosity, Commitment, and Critical Thinking

> "I know that it is possible to teach children to think creatively and that it can be done in a variety of ways. I have done it. I have seen my wife to it; I have seen other excellent teachers do it. I have seen children who had seemed previously to be "non-thinkers" learn to think creatively, and have seen them continuing for years thereafter to think creatively." (Ellis Paul Torrance; American psychologist; 1915-2003.)

Creativity, curiosity, commitment (stick-to-itiveness), and critical thinking are all important brain/mind traits. These traits are considered desirable, and so parents and teachers try to cultivate them in children. Before proceeding into this chapter, reflect on your own strengths and weaknesses in these areas. What has made you the way you are, and are you satisfied with how you are?

Creativity

Quoting from the Wikipedia:

> Creativity is a phenomenon whereby something new and valuable is created (such as an idea, a joke, an artistic or literary work, a painting or musical composition, a solution, an invention, etc.). The ideas and concepts so conceived can then manifest themselves in any number of ways, but most often, they become something we can see, hear, smell, touch, or taste.

E. Paul Torrance was a pioneer and world leader in the study of creativity. Learn more about Torrance from the article, E. Paul Torrance: His Life, Accomplishments, and Legacy (Hébert, et al., February, 2002). Quoting from the article:

> [Torrance's] interests in creativity began as he encountered difficult students as a high school teacher. Sensing their creative potential, he perceived these students to be more than problem children and wanted to understand more about the characteristics of creative individuals.
>
> …
>
> He developed a series of instruments designed to measure creativity, the most widely known, The Torrance Tests of Creative Thinking.

It is clear that some people are more creative than others. However, it requires a great deal of creativity just to participate in a meaningful back-and-forth conversation. So, a good place to start the study of human creativity is to assume that every intact human brain/mind is quite creative and has a great capacity for learning.

There is a substantial literature about creativity. My 5/24/2015 Google search of *creativity* returned more than 220 million hits. See, for example, the Torrance Center for Creativity and Talent Development. Quoting from the website:

> The Torrance Center™ for Creativity and Talent Development is a service, research, and instructional center concerned with the identification and development of creative potential and with gifted and future studies. Its goals are to investigate, implement, and evaluate techniques for enhancing creative thinking and to facilitate national and international systems that support creative development.

In this book on Brain Science, I have recommended a number of *TED Talks*. TED has a site titled Creativity in which it has gathered together more than 30 of its talks that relate to creativity (*TED Talks,* n.d.). This is a treasure trove! Quoting from the site:

> Where does creativity come from? How can you nurture your own? Watch *TED Talks* from creative people like Steve Jobs, architect Frank Gehry, designer Philippe Starck, writer Elizabeth Gilbert and more.

Creativity, Mental Illness, and the Science of Genius

Nancy Andreasen has spent many years doing research on possible relationships between creativity and mental illness. Her work is explored in the article, Secrets of the Creative Brain (Andreasen, 6/25/2014). Quoting from the article:

> I have spent much of my career focusing on the neuroscience of mental illness, but in recent decades I've also focused on what we might call the science of genius, trying to discern what combination of elements tends to produce particularly creative brains. What, in short, is the essence of creativity? Over the course of my life, I've kept coming back to two more-specific questions: What differences in nature and nurture can explain why some people suffer from mental illness and some do not? And why are so many of the world's most creative minds among the most afflicted? My latest study, for which I've been scanning the brains of some of today's most illustrious scientists, mathematicians, artists, and writers, has come closer to answering this second question than any other research to date.

Andreasen's article contains a number of interesting tidbits from other studies. She discusses the massive study begun in 1921, Genetic Studies of Genius by Lewis M. Terman, a Stanford psychologist whose work is one of the most legendary studies in American psychology. Drawing on Terman's longitudinal study of "geniuses" (IQ 135 and above), she says:

> But despite the implications of the title Genetic Studies of Genius, the Termites' [the people being studied] high IQs did not predict high levels of creative achievement later in life. Only a few made significant creative contributions to society; none appear to have demonstrated extremely high creativity levels of the sort recognized by major awards, such as the Nobel Prize.
>
> …
>
> Thirty percent of the men and 33 percent of the women did not even graduate from college. A surprising number of subjects pursued humble occupations, such as semiskilled trades or clerical positions. As the study evolved over the years, the term gifted was substituted for genius. Although many people continue to equate intelligence with genius, **a crucial conclusion from Terman's study is that having a high IQ is not equivalent to being highly creative.** Subsequent studies by other researchers have reinforced Terman's conclusions, leading to what's known as the threshold theory, which holds that above a certain level, intelligence doesn't have much effect on creativity: most

> creative people are pretty smart, but they don't have to be that smart, at least as measured by conventional intelligence tests. An IQ of 120, indicating that someone is very smart but not exceptionally so, is generally considered sufficient for creative genius. [Bold added for emphasis.]

Andreasen's research looks for possible distinguishing characteristics of creative minds. Here is a short quote from that section of her article:

> We examined focused episodic memory by asking subjects to recall a specific event that had occurred in the past and to describe it with their eyes closed. And we examined [using brain scanning equipment] a condition that we called random episodic silent thought, or REST: we asked subjects to lie quietly with their eyes closed, to relax, and to think about whatever came to mind. In essence, they would be engaged in "free association," letting their minds wander.

She is coming to the conclusion that random episodic silent thought (REST) is an important brain aspect of creativity. Ask yourself: Do you engage in free association, and do you find this helpful? Do you provide your students with instruction about free association as well as time and encouragement to use this brain technique?

Is Creativity Declining?

We can use the types of creativity measures developed by Torrance and others to look for changing patterns in creativity. There is some evidence that the average level of student creativity is declining (Retner, 8/12/2011). Quoting from this article:

> In a 2010 study of about 300,000 creativity tests going back to the 1970s, Kyung Hee Kim, a creativity researcher at the College of William and Mary, found creativity has decreased among American children in recent years. Since 1990, children have become less able to produce unique and unusual ideas. They are also less humorous, less imaginative and less able to elaborate on ideas, Kim said.
>
> ...
>
> Interestingly, scores on the Torrance test have been decreasing while SAT scores are increasing. However, better test scores do not necessarily translate to improved creativity, Kim said. **You can do well on a test by studying a lot, but it won't encourage original thinking.** [Bold added for emphasis.]

Retner is referencing a research paper by Kyung Hee Kim, Can Only Intelligent People Be Creative? A Meta-analysis. In the paper, Kim dispelled the myth that *intelligence* and *creativity* are the same, and her meta-analysis showed that there is only a negligible relationship between IQ and creativity test scores. This is consistent with Terman's study discussed above.

Personally, I believe that every student is creative. The day-to-day living and interacting with other people and the events of life require creativity. People are not automatons that function using a fixed, memorized set of "solutions" to the ongoing challenges they encounter.

Program for International Student Assessment

The most recent Program for International Student Assessment (PISA) is designed to measure 15-year-olds in math, science, and reading. In addition, it is designed to measure *creative problem solving* (Yettick, 4/1/2014). Quoting from the article:

> U.S. 15-year-olds scored above average on a first-of-its-kind international assessment that measured creative problem-solving skills.
>
> However, their mean scores were significantly lower than those earned in ten of the 44 countries and economies that took the Program for International Student Assessment (PISA) 2012 problem-solving assessment.
>
> The assessment, which was the subject of an Organization for Economic Cooperation and Development (OECD) report released Tuesday, **defined creative problem-solving as the ability to "understand and resolve problem situations where a method of solution is not immediately obvious."** Worldwide, a representative sample of 85,000 students took the exam, including 1,273 U.S. students in 162 schools. [Bold added for emphasis.]

The recent revision of PISA to include an emphasis on creative problem solving suggests a growing worldwide realization that this topic needs to be integrated into the curriculum. Think about a memorize-and-regurgitate approach to education versus learning for understanding and creatively using one's knowledge and skills. There is a growing awareness that the former and long-used approach to education is not meeting the needs of our current students and the world.

Teaching Creativity

What can we do to teach and/or to encourage student creativity? My 5/24/2015 Google search of the expression *teaching creativity* produced over 100 million results.

I highly recommend Robert Sternberg and Wendy Williams' article, Teaching for Creativity: Two Dozen Tips. This article draws heavily on Sternberg's Triatic Theory discussed in the previous chapter. Here are four of the two-dozen tips provided in the article (Sternberg & Williams, 1/1/2003).

> **• Model Creativity**
>
> The most powerful way to develop creativity in your students is to be a role model. Children develop creativity not when you tell them to, but when you show them.
>
> The teachers most of you probably remember from your school days are not those who crammed the most content into their lectures. The teachers you remember are those whose thoughts and actions served as your role model. Most likely they balanced teaching content with teaching you how to think with and about that content.
>
> Occasionally, we'll teach a workshop on developing creativity and someone will ask exactly how to develop creativity. Bad start. You cannot be a role model for creativity unless you think and teach creatively yourself. So think carefully about your values, goals, and ideas about creativity and show them in your actions.
>
> **• Define and Redefine Problems**
>
> Promote creative performance by encouraging your students to define and redefine problems and projects. Encourage creative thinking by having students choose their own topics for papers or presentations, choose their own ways of solving problems, and sometimes choose again if they discover that their selection was a mistake. Allow your students to pick their own topics, subject to your approval, on at least one paper each term. Approval ensures that the topic is relevant to the lesson and has a chance of leading to a successful project.

• Allow Mistakes

Schools are often unforgiving of mistakes. Errors on schoolwork are often marked with a large and pronounced X. When children respond to questions with incorrect answers, some teachers pounce on the students for not having read or understood the material and other students snicker. **When children go outside the lines in the coloring book, or use a different color, they are corrected. In hundreds of ways and in thousands of instances over the course of a school career, children learn that it is not all right to make mistakes. The result is that they become afraid to risk the independent and the sometimes-flawed thinking that leads to creativity.**

When your students make mistakes, ask them to analyze and discuss these mistakes. Often, mistakes or weak ideas contain the germ of correct answers or good ideas. In Japan, teachers spend entire class periods asking children to analyze the mistakes in their mathematical thinking. **For the teacher who wants to make a difference, exploring mistakes can be a learning and growing opportunity.** [Bold added for emphasis.]

• Teach Responsibility

Part of teaching students to be creative is teaching them to take responsibility for both success and failure. Teaching students how to take responsibility means teaching students to (1) understand their creative process, (2) criticize themselves, and (3) take pride in their best creative work.

If any of these ideas resonate with you, I strongly recommend that you read the full article by Sternberg and Williams.

Creativity in the Arts

You have probably heard some students say, "I can't do math," and others say, "I can't do art." From a math teacher's point of view, every student can learn to do math. From an artist's or art teacher's point of view, every person can learn to "create/do" and appreciate art. Susan Stauter, Artistic Director for the San Francisco Unified School District, wrote on this topic in the *IAE Newsletter* (Stauter, January, 2012). Quoting from her article:

> Our brain's basic task is to plan, regulate, and predict our movements, and to predict the movements of others and objects. Humans often add aesthetics to various movements and call it the Arts, a phenomenon deeply imbedded in human psyche and history. The artist articulates the culture—defining and challenging in ways that reflect personal truth but also become aesthetic cultural hallmarks. Those who wish to understand the history of a culture need to listen to its music, observe its clothing and architecture, and read its plays, poetry, and literature—all of which describe humans who are moving physically, emotionally, and intellectually.
>
> …
>
> Artists in the grip of the creative process often feel a level of obsession, with all of their energies going towards the solving of a creative riddle or the realization of an image, musical score, or choreographed movement pattern. The creative artist works around, over and through sometimes seemingly impossible obstacles. The drive to create is often fueled by an intense, obsessive energy that reaches its conclusion when the creative act is complete and the 'problem' seemingly solved, at least for the moment.

…

While some creative artists need to have long gestation periods before arriving at their creative product, others work quickly and actually thrive with pressure and difficult, short deadlines. One unifying driving force is the fact that the goal for the creator is high stakes; that is to say it matters a great deal. The resolution of the problem, the creation of the new work, is of greatest importance to the creative artist and acts as a driving force.

Art Education and Cognitive Development

The Dana Foundation supports a number of brain research projects (Rich, 3/4/2008). Here is some information about their project titled Learning, Arts, and the Brain. Quoting from the website:

> Learning, Arts, and the Brain, a study three years in the making, is the result of research by cognitive neuroscientists from seven leading universities across the United States. In the Dana Consortium study, released today at a news conference at the Dana Foundation's Washington, DC headquarters, researchers grappled with a fundamental question: **Are smart people drawn to the arts or does arts training make people smarter?**
>
> …
>
> The research was led by Dr. Michael S. Gazzaniga of the University of California at Santa Barbara. "A life-affirming dimension is opening up in neuroscience," said Dr. Gazzaniga, "to discover how the performance and appreciation of the arts enlarge cognitive capacities will be a long step forward in learning how better to learn and more enjoyably and productively to live. The consortium's new findings and conceptual advances have clarified what now needs to be done."
>
> Participating researchers, using brain imaging studies and behavioral assessment, identified eight key points relevant to the interests of parents, students, educators, neuroscientists, and policy makers.
>
> 1. An interest in a performing art leads to a high state of motivation that produces the sustained attention necessary to improve performance and the training of attention that leads to improvement in other domains of cognition.
> 2. Genetic studies have begun to yield candidate genes that may help explain individual differences in interest in the arts.
> 3. Specific links exist between high levels of music training and the ability to manipulate information in both working and long-term memory; these links extend beyond the domain of music training.
> 4. In children, there appear to be specific links between the practice of music and skills in geometrical representation, though not in other forms of numerical representation.
> 5. Correlations exist between music training and both reading acquisition and sequence learning. One of the central predictors of early literacy, phonological awareness, is correlated with both music training and the development of a specific brain pathway.
> 6. Training in acting appears to lead to memory improvement through the learning of general skills for manipulating semantic information.

7. Adult self-reported interest in aesthetics is related to a temperamental factor of openness, which in turn is influenced by dopamine-related genes.
8. Learning to dance by effective observation is closely related to learning by physical practice, both in the level of achievement and also the neural substrates that support the organization of complex actions. Effective observational learning may transfer to other cognitive skills. [Bold added for emphasis.]

Flow

> "The best moments in our lives are not the passive, receptive, relaxing times… The best moments usually occur if a person's body or mind is stretched to its limits in a voluntary effort to accomplish something difficult and worthwhile" (Mihaly Csikszentmihalyi; American psychologist; 1934-.)

Flow is a term coined by psychologist Mihalyi Csikszentmihalyi, an early proponent of positive psychology. His *TED Talks* (Csikszentmihalyi, February, 2004) is an excellent introduction to Csikszentmihalyi and *flow.* Jill Suttie provides more information in her article, Can Schools Help Students Find Flow? (Suttie, 4/16/2012). Quoting from her article:

> Since Csikszentmihalyi started studying flow more than 40 years ago, he and other researchers have found that it is associated with high levels of **creativity and optimal performance** in a wide variety of activities, and that it evokes feelings of happiness and even euphoria. They've observed benefits of flow among musicians, mountain climbers, basketball players, scientists, and many others.
>
> You can probably recall times you've experienced flow yourself—when you were "in the zone" on a sports field or when you were deeply engaged in a work project and the hours flew by like minutes.
>
> …
>
> But one place where we might not find too much flow these days, sadly, is in American schools. For years, the learning conditions in classrooms have been practically antithetical to the conditions people need to achieve flow and all the benefits that come with it. **Especially in the era of No Child Left Behind and high-stakes testing, schools have often favored regimentation over self-directed learning, making it harder for students to get deeply engaged with topics that interest them.** Paradoxically, these trends might be undermining the kind of student achievement they were designed to promote, and could even be causing student burnout. [Bold added for emphasis.]

I (David Moursund) have experienced flow while doing computer programming and often when I am writing. I have also experienced flow while giving professional talks and **while playing games.** I don't think my brain differentiates between flow achieved when playing a computer game and flow achieved during an academic pursuit such as writing or computer programming.

Many students and adults achieve a flow state through playing games. For such students, assigned school homework has a very hard time competing with game playing. Similar statements can also be made about participation in social networking. The Chapter 8 section on Addiction includes a discussion about computer games.

This material about creativity provides educators with a lot to think about. We value creativity and we want all of our students to become better, creative thinkers. We want them to use their creative thinking and problem-solving skills in each discipline they study and each area of human endeavor that engages them. So, use your own creativity to routinely engage your students in creative activities in their schoolwork. Help them to learn that they have considerable creative potential and to recognize this in themselves when they are using their creativity.

Curious Brain

> "The whole art of teaching is only the art of awakening the natural curiosity of young minds for the purpose of satisfying it afterwards." (Anatole France; French novelist and poet; 1844-1924.)

Curiosity is a strong desire to know or learn something. A child's healthy brain has a tremendous capability to learn. It is naturally curious and is always learning—and it learns at an amazing rate.

There is substantial research literature about curiosity. My 5/27/2015 Google search of the term *curiosity education* produced about 68 million hits. One of my favorite educational videos is Ken Robinson's *TED Talks,* How Schools Kill Creativity (Robinson, February, 2006). As of 6/3/2015, this talk had had more than 33 million total views!

In his talk, after giving several examples of children being creative, Robinson continues:

> What these things [stories] have in common is that kids will take a chance. If they don't know, they'll have a go. Am I right? They're not frightened of being wrong. Now, I don't mean to say that being wrong is the same thing as being creative. **What we do know is, if you're not prepared to be wrong, you'll never come up with anything original—if you're not prepared to be wrong. And by the time they get to be adults, most kids have lost that capacity. They have become frightened of being wrong.** And we run our companies like this, by the way. We stigmatize mistakes. And we're now running national education systems where mistakes are the worst thing you can make. **And the result is that we are educating people out of their creative capacities.** [Bold added for emphasis.]

It does not surprise me in the least that Robinson's 2006 talk has received so much attention. Reflect on your own education. And, if you are a parent, reflect on the education of your children. What do you think schools and parents should be doing to foster creativity?

We know that intellectual curiosity can be a driving force in education. Quoting from Why Curiosity Doesn't Kill the Cat (Chamorrro-Premuzic, 10/25/2011):

> Together with Sophie von Stumm and Benedikt Hell, we recently re-evaluated data from over 200 previous studies on ability, personality and academic performance, summarizing data from more than 50,000 students. We found that intellectual curiosity was a driving force in academic achievement. Specifically, the study showed that intellectual curiosity affected academic performance to the same extent as the personality trait Conscientiousness (a proxy for effort, albeit not a very good one), which is a well-established predictor of scholastic success. **Moreover, the impact of the two personality traits—intellectual curiosity and Conscientiousness—on academic**

> **performance rivaled that of intelligence.** That is, personality traits are core determinants of intellectual development and performance.
>
> …
>
> Children are naturally curious (ever heard the endless 'why' questions?) but few people have insatiable curiosity that cannot be dulled and blunted by dogmatism. Educational settings that don't give space to free exploration and 'why' questions, but solely dictate facts, easily suffocate a child's the spirit of wonder. Because curiosity is not only a trait but also a state, it is particularly important for schools and teachers to exploit their plentiful opportunities to induce and inspire curiosity in pupils and students. For one, curious students will perform better and for the other, students, who are intellectually stimulated, will more satisfied with their educational experience. [Bold added for emphasis.]

Think about the bolded statement in the quote. Intellectual creativity and effort are very important in learning. Cultivation of these two aspects of learning during childhood and early schooling can last a person for a lifetime. Certainly this should be one of the goals of informal and formal education.

Are you interested in assessing your own level of curiosity? See Oregon State University professor Anne-Marie Deitering's 30-question self-assessment test. Here is the first question:

When I see a complicated piece of machinery, I ask someone how it works.

1. Almost Never
2. Sometimes
3. Often
4. Almost Always

Here is a quote that summarizes a major long-term weakness in our educational system:

> "It is a miracle that curiosity survives formal education." (Albert Einstein; German-born theoretical physicist and 1921 Nobel Prize winner; 1879-1955.)

Much of our curriculum is presented in a manner that strongly suggests that the teacher and the text "know" both the questions to be asked and the answers to these questions. Moreover, with the increasing emphasis on high-stakes testing, some "powers that be" above the level of the teachers and texts is assuming responsibility for both the questions to be asked and the answers. This approach to education does not foster creativity on the part of students or their teachers.

Commitment (Stick-to-itiveness)

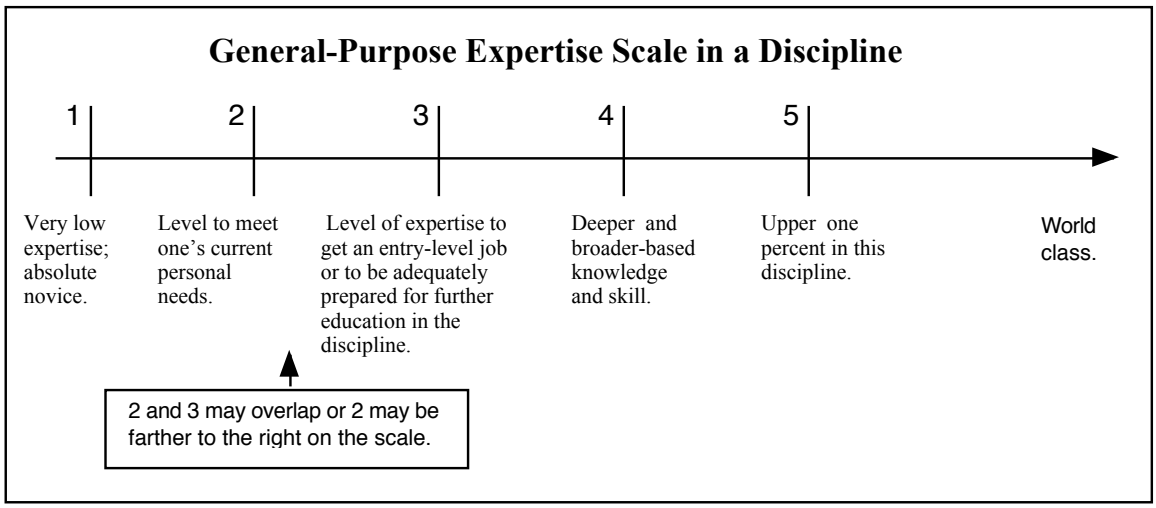
> "I have not failed. I've just found 10,000 ways that won't work." (Thomas A. Edison; American inventor and businessman; 1847-1931.)
>
> "If at first you don't succeed, try, try again. Then quit. There's no point in being a damn fool about it." (W. C. Fields; American comedian, actor, juggler, and writer; 1880-1946).

The two quotes taken together represent a key idea in solving problems, accomplishing tasks, and learning. The first emphasizes not giving up easily. The second is tongue-in-cheek humor. In

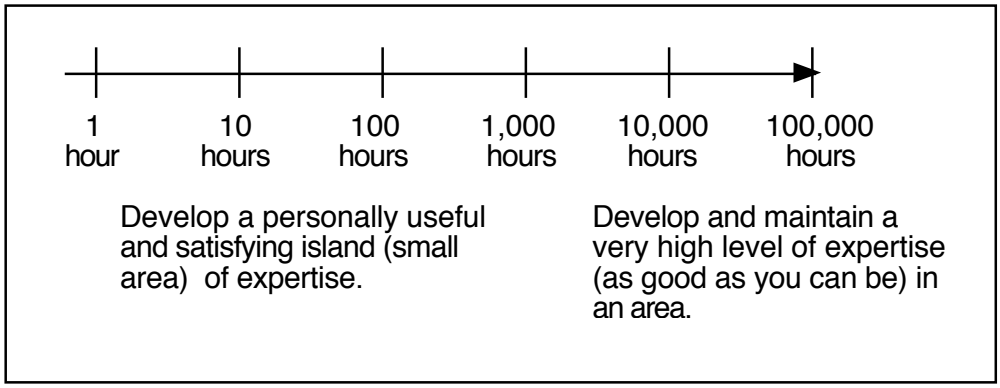
any given situation, each of us has a particular level of persistence or stick-to-itiveness. We make a personal decision about the time and effort we are willing to expend.

In each area of human endeavor and discipline of study we each begin with an initial level of expertise. A combination of nature and nurture applicable to the specific task being addressed helps to determine how rapidly we will progress and how far we can go.

Both of the diagrams given below are from David Moursund and Robert Albrecht's book, *Becoming a Better Math Tutor* (Moursund & Albrecht, 2011).



Expertise levels in a discipline or activity.



A scale of time needed to gain varying levels of expertise.

The first diagram illustrates the idea of how a person moves from being an absolute novice up to a higher and higher level of expertise. An increasing level of expertise comes from a combination of instruction, study, and practice. In school, students get the opportunity to repeatedly practice starting as a novice and moving up the expertise scale. They have the opportunity to build islands (small areas) of expertise in many different areas of study.

Here is a very important educational idea. We want students to develop self-confidence in their ability to start as a novice in an area that they want to learn and/or are expected to learn, and move toward greater expertise through personal effort. **This self-confidence comes from successful small steps in learning, and not by being beaten down by repeated failures.**

The second diagram is a time scale. A world-class performer in amateur sports generally has put in 10,000 hours of effort to achieve this level of performance. A doctorate in a field of study at a good university represents 10,000 or more hours of effort. A full professorship in a research university represents 20,000 to 30,000 hours of effort. To become a world-class chess player generally takes in the range of 20,000 to 30,000 hours of study and practice.

In all cases, to become world-class in an area takes a combination of nature and nurture. It also requires a high level of commitment and stick-to-itiveness.

True Grit

In recent years, the expression *true grit* has become popular in talking about having persistence, and the value of true grit in achieving success in various endeavors. A 5/27/2015 Google search of the expression *true grit education* produced nearly 800 thousand hits.

Angela Duckworth came up with the notion of *grit*—that very doggedness essential for success—and went on to receive a MacArthur Genius grant for her research. Quoting Angela Duckworth from her 2013 *TED Talks* (Duckworth, April, 2013):

> Grit is passion and perseverance for very long-term goals. Grit is having stamina. Grit is sticking with your future, day in, day out, not just for the week, not just for the month, but for years, and working really hard to make that future a reality. Grit is living life like it's a marathon, not a sprint. A few years ago, I started studying grit in the Chicago public schools. I asked thousands of high school juniors to take grit questionnaires, and then waited around more than a year to see who would graduate. Turns out that **grittier kids were significantly more likely to graduate,** even when I matched them on every characteristic I could measure, things like family income, standardized achievement test scores, even how safe kids felt when they were at school. So it's not just at West Point or the National Spelling Bee that grit matters. It's also in school, especially for kids at risk for dropping out. To me, the most shocking thing about grit is how little we know, how little science knows, about building it. Every day, parents and teachers ask me, "How do I build grit in kids? What do I do to teach kids a solid work ethic? How do I keep them motivated for the long run?" The honest answer is, I don't know. **What I do know is that talent doesn't make you gritty. Our data show very clearly that there are many talented individuals who simply do not follow through on their commitments.** In fact, in our data, grit is usually unrelated or even inversely related to measures of talent. [Bold added for emphasis.]

Quoting researcher David Yeager, a psychologist at the University of Texas (EWA, 6/11/2014):

> The research shows that even brief psychological interventions (a single 30-minute online exercise, for example) aimed at students' beliefs about their capacities to learn can have dramatic and long-lasting effects. The exercise explains to students that intelligence is not a biologically fixed trait, that they can actually develop and grow their brains through

> hard work. **Thus, a simple intervention can lead students to adopt a so-called "growth mindset" instead of a "fixed mindset."**
>
> These interventions have shown a transformative effect, particularly for at-risk students during educational transitions such as ninth grade or the first year of college. Students who have been educationally underserved because of race or socioeconomic status tend to underestimate their potential to succeed in the classroom, Yeager said. [Bold added for emphasis.]

In brief summary, the idea is to teach that intelligence can be developed—that, like a muscle, it grows with hard work and good strategies. Teachers and parents can help students view struggles in school not as a threat ("Am I dumb?") but as an opportunity to grow and learn ("This will make my brain stronger!").

Amy Lyon's short video, Teaching Grit: How to Help Students Overcome Inner Obstacles, illustrates what a fifth grade teacher has accomplished with her students (Lyon, 4/20/2014). Quoting from the website:

> Amy Lyon, the teacher in the grit video above, created a yearlong grit curriculum based on Martin Seligman's book The Optimistic Child. Pointing to years of research, Seligman argues that optimism is a skill that can be taught by changing how we view the setbacks we encounter in life. He also notes that parents and teachers must model and teach these skills, because children learn either pessimism or optimism from the adults in their lives.

Delayed Gratification and Self-discipline

You have heard about the concepts of instant gratification and delayed gratification. Indeed, you can probably do a good job of self-analysis in these areas by comparing yourself with other people you know. Are you better or worse than your friends in saving money (delayed gratification) instead of building up large credit card debts (instant gratification)? When you make a New Year's resolution or decide to get more exercise, do you carry out your resolution (self-discipline)?

The topic of self-gratification gained fame through the work of Walter Mischel. For an interesting discussion of his work see Maria Konnikova's article, Mischel, The Struggle of a Psychologist Studying Self-control (Konnikova, 10/9/2014).

Mischel conducted experiments that came to be called the Marshmallow Test. Joachim de Posada's video, Don't Eat the Marshmallow, shows young children struggling with whether to immediately eat an available marshmallow or to wait and receive a reward of a second marshmallow (de Posada, February, 2009).

Much of current formal education asks students to delay gratification and use academic self-discipline. When a student asks, "Why do I need to learn this?" a frequent response is, "You're going to need it next year." A variation on this is, "You'll need it later on in life." A common third reason nowadays is, "It is going to be on the test." Many students are masters in being able to convince themselves that they would rather to "almost anything" other than homework.

Many of the answers to "Why do I need to…" questions provided by parents and teachers are extrinsic motivation answers. "It's going to be on the test" is cogent only if the student cares about getting good grades or high scores, parental approval, admission into college, etc.

"You're going to need it next year" invites the obvious question, "Why can't I learn it when I have some immediate use to know it?" For more on this discussion, see the next section on Learning, Forgetting, and Relearning.

More than at any time in the past, today's students in "affluent" countries such as the United States live in a world of instant gratification. Not only that, they are barraged with ads telling them what they need in order to be gratified.

We have long known that a desire for instant gratification is not conducive to learning academic areas that require concerted efforts over a long period of time. Math provides an excellent example. The following quote is from Jonah Lehrer's article, Don't: The Secret of Self Control (Lehrer, 5/18/2009):

> [Angela Lee Duckworth] first grew interested in the subject [of self-control] after working as a high-school math teacher. "For the most part, it was an incredibly frustrating experience," she says. "I gradually became convinced that trying to teach a teen-ager algebra when they don't have self-control is a pretty futile exercise." And so, at the age of thirty-two, Duckworth decided to become a psychologist. One of her main research projects looked at the relationship between self-control and grade point average. She found that the ability to delay gratification—eighth graders were given a choice between a dollar right away or two dollars the following week—was a far better predictor of academic performance than I.Q. **She said that her study shows that "intelligence is really important, but it's still not as important as self-control."** [Bold added for emphasis.]

Study Skills: Learning, Forgetting, and Relearning

We know that students forget much of what they "learn" in a course. This occurs through disuse of the materials, the "rote memory, regurgitate for the test, and forget" approach, teaching methods that are not as good as they can be in facilitating "deep learning with understanding," and so on.

A 5/29/2015 Google search of the expression *learning and forgetting* produced over 28 million hits. The UCLA Bjork Learning & Forgetting Lab was at the top of the list (UCLA, 2015). The Research section of the site provides an extensive introduction to and overview of learning and forgetting, including a number of five-to-seven minute video presentations by Bjork. The videos contain research-based recommendations to teachers and students. The video topics, along with my comments of very brief highlights of each video, are given below.

- **Using our memory shapes our memory.** To remember and be able to retrieve a piece of information over time, learn it well and use it over time. Using retrieved information strengthens its ability to be retrieved. Provides good insight into studying for tests, and the value of self-testing or students testing each other in study groups.
- **Retrieval induced forgetting.** This explores a theory that repeatedly retrieving several items from a group produces interference that makes it harder to retrieve other items from the same group.
- **The theory of disuse and the role of forgetting in human memory.** Disuse of well-learned information does not lead to it disappearing from one's brain. Rather, it makes it more difficult to retrieve. Relearning occurs quickly as one practices retrieving the "lost" information

- **Storage strength versus retrieval strength.** The theory discussed here is that if you learn something well, (build storage strength) it stays with you forever. What degrades over time is retrieval strength. The decreasing retrieval strength coming from disuse cuts down on interference as one tries to recall somewhat related, but more recently used information.
- **Desirable difficulties: slowing down learning.** This video compares and contrasts examples of techniques for quickly learning information (ones that often produce poor long-term retention) versus less quick-study techniques that can lead to better long-term retention.
- **Spacing improves long-term retention.** The first research suggesting that the value of spacing one's study times produces better long-term retention was done in 1885. Spacing is a robust finding. But, Bjork also notes the value of cramming for a test when a student's goal is to pass a test and the student is not much concerned about long-term retention. (This might be thought of as a situation in which the instant gratification of scoring well on a test outweighs the longer term gratification of gaining long-lasting knowledge and skills.)
- **The benefits of interleaving practice.** Suppose one has several different things to learn. This video compares block practice (practicing the first thing over and over, then the second thing, and so on) versus interleaved practice (the same total amount of practice, but do a little on the first, a little on the second, and so on, and repeat this cycle a number of times). It turns out that for long-term retention in both physical and cognitive learning, interleaving is better.

A major focus of the Bjork lab's research is directed toward understanding the mechanisms behind metacognitive awareness of learning. Quoting from the website:

> The goal of these studies is to determine the type of instructions and study conditions that will foster accurate judgments of learning [self-assessment], which can lead to better predictions of future performance and optimal self-initiated study practices.

Metacognition and reflection techniques can be learned even at the kindergarten level. These are valuable tools for all students.

A great deal of research has been done on how quickly students forget information that has been presented to them and they have learned at some level. C. Frank Starmer's article, About Education: Fundamental Concepts of Forgetting and Learning, provides information about how quickly we forget (Starmer, n.d.). Quoting from the article:

> On Day 1, at the beginning of the lecture, you go in knowing nothing, or 0%, (where the [learning] curve starts at the baseline). At the end of the lecture you know 100% of what you know, however well you know it (where the curve rises to its highest point).
>
> By Day 2, if you have done nothing with the information you learned in that lecture, didn't think about it again, read it again, etc. **you will have lost 50%-80%** of what you learned. Our brains are constantly recording information on a temporary basis: scraps of conversation heard on the sidewalk, what the person in front of you is wearing. Because the information isn't necessary, and it doesn't come up again, our brains dump it all off, along with what was learned in the lecture that you actually do want to hold on to!

> By Day 7, we remember even less, and **by Day 30, we retain about 2%-3% of the original [first] hour!** This nicely coincides with midterm exams, and may account for feeling as if you've never seen this before in your life when you're studying for exams - you may need to actually re-learn it from scratch.
>
> …
>
> Here's the formula, and the case for making time to review material: Within 24 hours of getting the information, spend 10 minutes reviewing and you will raise the curve almost to 100% again. A week later (Day 7), it only takes 5 minutes to "reactivate" the same material, and again raise the curve. By Day 30, your brain will only need 2-4 minutes to give you the feedback, "Yup, I know that. Got it." [Bold added for emphasis.]

In summary, we now know a great deal about effective study skills and about how use of ineffective study skills leads to forgetting most of what has been studied. Some teachers spend time helping their students to learn study skills that are particularly effective in the discipline they are teaching and/or that are effective across many disciplines. Research indicates that this is a good thing to do!

Interestingly, our current emphasis on teaching to the test, learning test-taking skills, and having students learn to study in a manner designed specifically to quickly increase one's test scores are all poor approaches to gaining long-lasting understanding and knowledge.

You and Your Students

All of the brain-related topics covered in this chapter are student brain/mind abilities that are somewhat directly under a student's control. Through instruction and practice, a student can become better in each of the areas of creativity, curiosity, commitment, and critical thinking. In each of these areas we want students to develop habits of mind that are conducive to doing well in school and in life after school.

Look back to how this chapter began. You can use the same technique—asking students to self-assess some of their habits of mind—to get your students involved in thinking about these ideas. Any one of the main ideas of this chapter can be used in metacognition (personal reflection), small group discussions, and whole class discussions. Each can be self-assessed.

So, one of your goals as a teacher is to help your students become consciously aware of their own ideas and underlying personal values. Create a classroom environment that encourages students to monitor their own behavior and that supports developing and using these brain/mind habits.

References and Resources for Chapter 6

Andreasen, N. (6/25/2014). Secrets of the creative brain. *The Atlanti*c. Retrieved 5/24/2015 from http://www.theatlantic.com/features/archive/2014/06/secrets-of-the-creative-brain/372299/. Quoting from the article:

> For many of my subjects from that first study—all writers associated with the Iowa Writers' Workshop—mental illness and creativity went hand in hand. This link is not surprising. The archetype of the mad genius dates back to at least classical times, when Aristotle noted, "Those who have been eminent in philosophy, politics, poetry, and the arts have all had tendencies toward melancholia."

Chamorrro-Premuzic, T. (10/25/2011). Why curiosity doesn't kill the cat. *Psychology Today*. Retrieved 5/25/2015 from https://www.psychologytoday.com/blog/mr-personality/201110/why-curiosity-doesn-t-kill-the-cat. Quoting from the article:

> Psychological studies have demonstrated that effort and ability explain about half of the variance in academic performance—but what's with the other half?
>
> The answer may lie with a bridging construct, a trait that drives the application of both ability and effort: intellectual curiosity.

Csikszentmihalyi, M. (February, 2004). Flow, the secret to happiness. (Video, 18:55.) *TED Talks*. Retrieved 5/29/2015 from http://www.ted.com/talks/mihaly_csikszentmihalyi_on_flow. Quoting from the website:

> Mihaly Csikszentmihalyi asks, "What makes a life worth living?" Noting that money cannot make us happy, he looks to those who find pleasure and lasting satisfaction in activities that bring about a state of "flow."

de Posada, J. (February, 2009). Don't eat the marshmallow. (Video, 5:58.) *TED Talks*. Retrieved 6/20/2015 from http://www.ted.com/talks/joachim_de_posada_says_don_t_eat_the_marshmallow_yet?language=en. Quoting from the website:

> In this short talk from TED U, Joachim de Posada shares a landmark experiment on delayed gratification — and how it can predict future success. With priceless video of kids trying their hardest not to eat the marshmallow.

Duckworth, A. (April, 2013). The key to success? Grit. (Video, 6:12.) *TED Talks*. Retrieved 5/27/2015 from http://www.ted.com/talks/angela_lee_duckworth_the_key_to_success_grit?language=en#t-172495. Quoting from the website:

> At the University of Pennsylvania, Angela Lee Duckworth studies intangible concepts such as self-control and grit to determine how they might predict both academic and professional success.

EWA (6/11/2014). Researchers: Don't over-hype 'grit' as a student success factor. *Blog: The Educated Reporter*. Retrieved 5/27/2015 from http://www.ewa.org/blog-educated-reporter/researchers-dont-over-hype-grit-student-success-factor. Quoting from the website:

> At EWA's 67th National Seminar at Vanderbilt University last month, we took a "deep dive" into the impact of noncognitive factors on student learning.
>
> There's been an explosion of interest in recent findings on the role of mindset and "grit" in student success. But along with this enthusiasm comes real concern by researchers.

Hébert, T.P., et al. (February, 2002). E. Paul Torrance: His life, accomplishments, and legacy. Retrieved 5/24/2015 from http://files.eric.ed.gov/fulltext/ED505439.pdf. Quoting from the document:

> This monograph is presented in three sections which include a discussion of Torrance's life, followed by an overview of his accomplishments, including his creativity research, the Future Problem Solving Program, and the Incubation Model of Teaching.

Kim, K.H. (Winter/Spring, 2005). Can only intelligent people be creative? A meta-analysis. *JSGE.* Retrieved 6/20/12015 from http://www.eric.ed.gov/PDFS/EJ698316.pdf. Quoting from the article:

> Some research has shown that creativity test scores are independent from IQ scores, whereas other research has shown a relationship between the two. To clarify the cumulative evidence in this field, a quantitative review of the relationship between creativity test scores and IQ scores was conducted.

Konnikova, M. (10/9/2014). The struggle of a psychologist studying self-control. *The New Yorker*. Retrieved 6/3/2015 from http://www.newyorker.com/science/maria-konnikova/struggles-psychologist-studying-self-control**.**

Learn some of the back-story of Walter Mischel, who developed the Marshmallow Test for delayed gratification and continued his research in this area throughout his long career. In 2014, at the age of 84, Michel published his first book—*The Marshmallow Test: Mastering Self-Control.*

Lehrer, J. (5/18/2009). Don't: The secret of self control. *The New Yorker.* Retrieved 5/28/2015 from http://www.newyorker.com/magazine/2009/05/18/dont-2?currentPage=all.

This article focuses on both the marshmallow test and other important research work of Walter Mischel. In one example of his research, "[Peace Corps volunteers] were tested for standard personality traits, and Mischel compared the results with ratings of how well the volunteers performed in the field. He found no correlation; the time-consuming tests predicted nothing."

Lyon, A. (4/20/2014). Teaching grit: How to help students overcome inner obstacles. (Video, 6:20.) *Edutopia.* Retrieved 5/27/2015 from http://www.edutopia.org/blog/grit-help-students-overcome-inner-obstacles-vicki-zakrzewski.

Watch teacher Amy Lyon help her 5th graders learn valuable lessons about how to deal with frustration and distractions as they set and work toward long-term goals.

Moursund, D., & Albrecht, R. (2011). *Becoming a better math tutor.* Eugene, OR: Information Age Education. Download PDF file from http://i-a-e.org/downloads/free-ebooks-by-dave-moursund/208-becoming-a-better-math-tutor.html. Download Microsoft word file from http://i-a-e.org/downloads/free-ebooks-by-dave-moursund/209-becoming-a-better-math-tutor-1.html.

This book is designed to help math tutors and tutees to become better at their respective and mutual tasks. The intended audiences for this book include volunteer and paid tutors, preservice and inservice teachers, parents and other child caregivers, students who help other students (peer tutors), and developers of tutorial software and other materials.

Retner, R. (8/12/2011). Not your imagination: Kids today really are less creative, study says. *Today Parenting.* Retrieved 6/4/2015 from http://today.msnbc.msn.com/id/44122383/ns/today-parenting/t/not-your-imagination-kids-today-really-are-less-creative-study-says/#.TopGcnNYfe6. Quoting from the article:

> "It's not that creativity can necessarily disappear," said Ron Beghetto, an education psychologist at the University of Oregon. "But it can be suppressed in particular contexts."

> The current focus on testing in schools, and the idea that there is only one right answer to a question, may be hampering development of creativity among kids, Beghetto said.

Rich, B. (3/4/2008). Strong links between arts education and cognitive development. Dana Foundation. Retrieved 6/4/2015 from http://www.dana.org/News/Details.aspx?id=43417.

This is a report on a very large study. Although "there is still a lot of work to be done," says Dr. Gazzaniga, the consortium's research so far has clarified the way forward. "We now have further reasons to believe that training in the arts has positive benefits for more general cognitive mechanisms."

Robinson, K. (February, 2006). How schools kill creativity. (Video, 19:24.) *TED Talks.* Retrieved 5/25/2015 from http://www.ted.com/talks/ken_robinson_says_schools_kill_creativity. Quoting from the website:

> Creativity expert Sir Ken Robinson challenges the way we're educating our children. He champions a radical rethink of our school systems, to cultivate creativity and acknowledge multiple types of intelligence.

Starmer, C.F. (n.d.). About education: Fundamental concepts of forgetting and learning. Retrieved 6/3/2015 from https://frank.itlab.us/forgetting/. [Note from David Moursund: To make this address work, I had to copy the address and paste it into my browser.] Quoting from the site:

> With this page, I am accumulating resources and links to other sites that address the neurobiology of forgetting. Basing our educational paradigm on what is known about forgetting, I can evolve a 21st century educational paradigm that amplifies available energy for thinking by not devoting energy on memorizing rarely used facts and concepts and instead, depending on rapid retrieval of Internet accessible resources.

Stauter, S. (January, 2012). Creating an appropriate 21st century education: The positive roles that the arts, arts education, and creative obsession will play. *IAE Newsletter.* Retrieved 5/25/2015 from http://i-a-e.org/newsletters/IAE-Newsletter-2012-81.html. Quoting from the newsletter:

> An overwhelming number of K-12 Arts Education programs faded or disappeared in the United States during the last part of the 20th century. At the same time, the cultural role of the arts in society increased. This article will argue that the disconnect occurred in part because K-12 arts education got untracked by standards and assessment programs that misunderstood the role of arts in education and society.

Sternberg, R., & Williams, W. (1/1/2003). Teaching for creativity: Two dozen tips. The Center for Development & Learning. Retrieved 5/24/2015 from http://www.cdl.org/articles/teaching-for-creativity-two-dozen-tips/. Quoting from the article:

> What makes a person creative? Why are some people more creative and others less so? We often think that the creative people are the ones who have some rare and unattainable ability, but it is not so.

Suttie, J. (4/16/2012). Can schools help students find flow? *Greater Good.* Retrieved 5/25/2015 from http://greatergood.berkeley.edu/article/item/can_schools_help_studnts_find_flow. Quoting from the article:

> In a 2001 study David Shernoff ran with education researcher Lisa Hoogstra, he found that students who experienced more flow in high school science classes were more likely to major in science in college two years later. What's more, their academic performance in college was better predicted by whether they experienced flow than by the grades they received in those high school classes.

TED Talks (n.d.). Creativity. (Video series.) *TED Talks.* Retrieved 5/24/2015 from https://www.ted.com/topics/creativity.

This site provides links to more than 30 *TED Talks* related to creativity.

- 8 talks: Where do ideas come from?
- 6 talks: The creative spark.
- 11 talks: What is success?
- 8 talks: The Remix.

UCLA (2015). Bjork Learning & Forgetting Lab. (8 short videos). Retrieved 5/29/2015 from http://bjorklab.psych.ucla.edu/research.html#rif. Quoting from the website:

> The primary goal of this research, which is funded by the James S. McDonnell foundation, is to promote learning and memory performance within educational contexts through the investigation of principles in cognitive psychology. Studies address issues of transfer-appropriate and material-appropriate processing between encoding and retrieval.

Yettick, H. (4/1/2014). U.S. students score above average on first PISA problem-solving exam. *Education Week*. Retrieved 9/2/2014 from http://blogs.edweek.org/edweek/inside-school-research/2014/04/pisa_problem_solving.html. Quoting from the article:

> In modern societies, all of life is problem solving," states the report "PISA 2012 Results…. Complex problem-solving skills are particularly in demand in fast-growing, highly skilled managerial, professional, and technical occupations."

Chapter 7. Consciousness, Dreaming, Free Will, Hypnosis, Sleep Learning, and Meditation

> "Properly speaking, the unconscious is the real psychic; its inner nature is just as unknown to us as the reality of the external world, and it is just as imperfectly reported to us through the data of consciousness as is the external world through the indications of our sensory organs." (Sigmund Freud; Austrian neurologist, now known as the father of psychoanalysis; 1856-1937.)

> "True philosophy must start from the most immediate and comprehensive fact of consciousness: 'I am life that wants to live, in the midst of life that wants to live.'" (Albert Schweitzer; German—and later French—theologian, philosopher, physician, and medical missionary in Africa; 1875-1965.)

> "I believe consciousness is brazenly physical, a raucous mirage the brain creates to help us survive. But I also sense the universe is magical, greater than the sum of its parts, which I don't attribute to a governing god, but simply to the surprising, ecstatic, frightening everyday reality we all know. Ultimately, I find consciousness a fascinating predicament for matter to get into." (Diane Ackerman; American poet, essayist, and naturalist; 1948-.)

This chapter contains introductions to a variety of additional brain science and education oriented topics. Each topic is an ongoing area of research contributing to a better understanding of the human brain. Each might be expanded in a future edition of this book.

Consciousness

My 6/25/2015 Google search of the term *consciousness* produced over 86 million results. Quoting from the Wikipedia:

> Consciousness is the quality or state of awareness, or, of being aware of an external object or something within oneself. It has been defined as: sentience, awareness, subjectivity, the ability to experience or to feel, wakefulness, having a sense of selfhood, and the executive control system of the mind. Despite the difficulty in definition, many philosophers believe that there is a broadly shared underlying intuition about what consciousness is. As Max Velmans and Susan Schneider wrote in The Blackwell Companion to Consciousness: "Anything that we are aware of at a given moment forms part of our consciousness, making conscious experience at once the most familiar and most mysterious aspect of our lives."

Consciousness is one of the major challenging problems in brain science. Progress is being made in understanding how the collection of cells in a brain has consciousness. We have a conscious "self" when awake. You and I go to sleep, and lose both our consciousness and our awareness of self. We awaken and both return. What a challenging mystery!

Michio Kaku, in his book *The Future of the Mind,* presents a unifying model of consciousness (Kaku, 2014). Quoting from his book:

> Consciousness is the process of creating a model of the world using multiple feedback loops in various parameters (e.g., in temperature, space, time, and in relation to others), in order to accomplish a goal (e.g., find mates, food, shelter). I call this a "space-time theory of consciousness," because it emphasizes the idea that animals create a model of the world mainly in relation to space, and to one another, while humans go beyond and create a model of the world in relation to time, both forward and backward.

The four levels of consciousness considered by Kaku can be summarized as:

Level 0: The consciousness of a plant or other organism that has no mobility or very limited mobility. It creates a model that has very few parameters (e.g., temperature, light). The sensing and feedback loops in a plant are sufficient to facilitate survival and reproduction.

Level 1: The consciousness of a creature that has a central nervous system, such as an insect or reptile. It is able to create models for movement in space. This requires awareness of space, and relationships between itself and other objects in space. The creature may have vision and other senses such as hearing, smell, touch, and taste. (One part of a human brain is called the reptilian brain.)

Level 2: A consciousness that can create models of its relationship between others of its kind—for example, emotional and social relationships. Dogs, cats, and many other animals have this level of consciousness.

Level 3: A consciousness that has an awareness of time, itself, and its host (body). It has the ability to create mental simulations of the future and its host's participation in these simulated futures. Quoting Kaku again:

> "Human consciousness is a specific form of consciousness that creates a model of the world and then simulates it in time, by evaluating the past to simulate the future. This requires mediating and evaluating many feedback loops in order to make a decision to achieve a goal."

Kaku's model of four levels of consciousness can be used to analyze computers. Today's computers have not yet reached Level 2. While the artificial intelligence of computers can outperform humans in many areas, the computers have a long way to go before they achieve Level 3 consciousness.

As Kaku and others point out, there are many possible definitions of consciousness. Some researchers start at the level of a single cell, and argue that a single cell has a type of consciousness. Quoting from Bruce Lipton's article, Insight into Cellular Consciousness (Lipton, 2001):

> …there are no physiologic functions in our bodies that were not already pre-existing in the biology of the single, nucleated (eukaryotic) cell. Single-celled organisms, such as the amoeba or paramecium, possess the cytological equivalents of a digestive system, an excretory system, a respiratory system, a musculoskeletal system, an immune system, a reproductive system and a cardiovascular system, among others. In the humans, these physiologic functions are associated with the activity of specific organs. These same

> physiologic processes are carried out in cells by diminutive organ systems called organelles.
>
> …
>
> Studies on cloned human cells led me to the awareness that the cell's plasmalemma, commonly referred to as the cell membrane, represents the cell's "brain." Cell membranes, the first biological organelle to appear in evolution, are the only organelle common to every living organism.

There is substantial written and video material about consciousness. Three excellent video examples are given below.

John Searle: Our Shared Condition—Consciousness (Searle, July, 2013). Quoting from the beginning of the video:

> I'm going to talk about consciousness. Why consciousness? Well, it's a curiously neglected subject, both in our scientific and our philosophical culture.
>
> Now why is that curious? Well, **it is the most important aspect of our lives for a very simple, logical reason, namely, it's a necessary condition on anything being important in our lives that we're conscious.** You care about science, philosophy, music, art, whatever -- it's no good if you're a zombie or in a coma, right? So consciousness is number one. The second reason is that when people do get interested in it, as I think they should, they tend to say the most appalling things. And then, even when they're not saying appalling things and they're really trying to do serious research, well, it's been slow. Progress has been slow. [Bold added for emphasis.]

In his talk, Searle addresses the belief of many philosophers that "consciousness is an illusion." In essence, he says this is nonsense.

Dan Dennett: The Illusion of Consciousness (Dennett, February, 2003). Quoting from his talk:

> It's very hard to change people's minds about something like consciousness, and I finally figured out the reason for that. The reason for that is that everybody's an expert on consciousness. We heard the other day that everybody's got a strong opinion about video games. They all have an idea for a video game, even if they're not experts. But they don't consider themselves experts on video games; they've just got strong opinions. I'm sure that people here who work on, say, climate change and global warming, or on the future of the Internet, encounter people who have very strong opinions about what's going to happen next. But they probably don't think of these opinions as expertise. They're just strongly held opinions. But with regard to consciousness, people seem to think, each of us seems to think, "I am an expert. Simply by being conscious, I know all about this." And so, you tell them your theory and they say, "No, no, that's not the way consciousness is! No, you've got it all wrong." And they say this with an amazing confidence.
>
> …
>
> …what you are, what I am—is approximately 100 trillion little cellular robots. That's what we're made of. No other ingredients at all. We're just made of cells, about 100 trillion of them. Not a single one of those cells is conscious; not a single one of those cells knows who you are, or cares. Somehow, we have to explain how when you put

> together teams, armies, battalions of hundreds of millions of little robotic unconscious cells—not so different really from a bacterium, each one of them—the result is this. I mean, just look at it. The content—there's color, there's ideas, there's memories, there's history. And somehow all that content of consciousness is accomplished by the busy activity of those hoards of neurons. How is that possible? Many people just think it isn't possible at all. They think, "No, there can't be any sort of naturalistic explanation of consciousness."

Dennett goes on to discuss the idea from various religions that, in addition to the 100 trillion cells, there is a *soul* that resides in one's body and leaves (perhaps going to heaven, purgatory, or hell) when one dies.

Antonio Damasio: The Quest to Understand Consciousness (Damasio, March, 2011). Quoting from the beginning of Damasio's talk:

> I'm here to talk about the wonder and the mystery of conscious minds. The wonder is about the fact that we all woke up this morning and we had with it the amazing return of our conscious mind. **We recovered minds with a complete sense of self and a complete sense of our own existence**, yet we hardly ever pause to consider this wonder. We should, in fact, because without having this possibility of conscious minds, we would have no knowledge whatsoever about our humanity; we would have no knowledge whatsoever about the world. We would have no pains, but also no joys. We would have no access to love or to the ability to create. And of course, Scott Fitzgerald said famously that "he who invented consciousness would have a lot to be blamed for." But he also forgot that without consciousness, he would have no access to true happiness and even the possibility of transcendence.
>
> …
>
> So in order to have a conscious mind, you have a self within the conscious mind. So a conscious mind is a mind with a self in it. The self introduces the subjective perspective in the mind, and we are only fully conscious when self comes to mind. So what we need to know to even address this mystery is, **number one, how our minds are put together in the brain, and, number two, how selves are constructed.** [Bold added for emphasis.]

Christof Koch discusses recent progress in understanding consciousness in his article, Neuronal "Superhub" Might Generate Consciousness (Koch, 10/16/2014). Quoting from the article:

> …the clinical team made a remarkable observation: electrically stimulating a single site with a fairly large current abruptly impaired consciousness in 10 out of 10 trials—the patient stared blankly ahead, became unresponsive to commands and stopped reading. As soon as the stimulation stopped, consciousness returned, without the patient recalling any events during the period when she was out. **Note that she did not become unconscious in the usual sense, because she could still continue to carry out simple behaviors for a few seconds if these were initiated before the stimulation started—behaviors such as making repetitive tongue or hand movements or repeating a word.** Koubeissi was careful to monitor electrical activity throughout her brain to confirm that episodes of loss of consciousness did not accompany a seizure.

> …
>
> Here consciousness as a whole appeared to be turned off and then on again. Second, it happened only at a single place, in the white matter close to the claustrum and the cortex. Because electrical stimulation of the nearby insula is not known to elicit a loss of consciousness, the researchers implicated the claustrum. [Bold added for emphasis.]

The topics of consciousness and education are combined in some schools/teachings in what is called *consciousness-based education* or *transcendental meditation.* Here are several quotes that help to define the ideas of conscious-based education.

> "The key to growth is the introduction of higher dimensions of consciousness in our awareness." (Lao Tsu; Chinese philosopher; 6th century BC.)
>
> "The highest education is that which does not merely give us information but makes our life in harmony with all existence." (Rabindranath Tagore; Indian poet; 1861-1941.)
>
> "Know that consciousness by which all else is known." (Mahesh Prasad Varma; Maharishi Mahesh Yogi; 1918-2008.)

Quoting from the Wikipedia:

> Transcendental Meditation in education (also known as **Consciousness-Based Education**) is the application of the Transcendental Meditation technique in an educational setting or institution. These educational programs and institutions have been founded in the USA, United Kingdom, Australia, India, Africa and Japan. The Transcendental Meditation technique became popular with students in the 1960s and by the early 1970s centers for the Students International Mediation Society were established at a thousand campuses. [Bold added for emphasis.]

For more information about consciousness and education, see Robert Sylwester and David Moursund's book, *Consciousness and Morality: Recent Research Developments* (Sylwester & Moursund, June, 2013). This short (48-page) book provides an introduction to consciousness and explores the question of how consciousness and morality are related. Here are four of the chapter titles:

Chapter 1. Emotions, Feelings, and Consciousness.

Chapter 2. Consciousness and Free Will.

Chapter 6. The Search for Moral Behavior in Mammals.

Chapter 7. Philosophical/Theological Perspectives on Consciousness and Morality.

Dreaming and Education

Chapter 9 discusses sleep disorders and sleep deprivation. Dreaming is a natural and important part of sleeping. Dream deprivation can cause serious brain degradation. My 6/14/2015 Google search of the term *health benefits of dreaming* returned over 1.5 million results, and my Google search of the term *dream research* returned over 200 million results.

You might wonder whether dreaming is commonplace. Quoting from the *International Association for the Study of Dreams* (IASD, n.d.):

> **Does everyone dream?Michael**

> Yes. Laboratory studies have shown that we experience our most vivid dreams during a type of sleep called Rapid Eye Movement (REM) sleep. During REM sleep the brain is very active, the eyes move back and forth rapidly under the lids, and the large muscles of the body are relaxed. REM sleep occurs every 90 - 100 minutes, 3 to 4 times a night, and lasts longer as the night progresses. The final REM period may last as long as 45 minutes. Less vivid dreams occur at other times during the night.

Dreams and dreaming are a popular topic in the media. See, for example, What Are Dreams? (NOVA, 9/15/2012). In this 55-minute video, NOVA draws on a wide range of resources to help answer the question: What are dreams? The video provides answers to this and a number of other questions. Quoting from the website:

> NOVA joins leading dream researchers as they embark on a variety of neurological and psychological experiments to investigate the world of sleep and dreams. Delving deep into the thoughts and brains of a variety of dreamers, scientists are asking important questions about the purpose of this mysterious realm we escape to at night. Do dreams allow us to get a good night's sleep? Do they improve memory? Do they allow us to be more creative? Can they solve our problems or even help us survive the hazards of everyday life?

Sander van der Linden's article, The Science Behind Dreaming, provides a good introduction to how and why we remember dreams (Linden, 7/26/2011). It begins by noting that interest in dreams and their possible meanings goes back thousands of years. In more recent time, Sigmund Freud and Carl Jung and wrote extensively about dreams. Quoting from the article:

> Freud's theory centered around the notion of repressed longing—the idea that dreaming allows us to sort through unresolved, repressed wishes. Carl Jung (who studied under Freud) also believed that dreams had psychological importance, but proposed different theories about their meaning.
>
> …
>
> The proposed link between our dreams and emotions is also highlighted in another recent study published by Matthew Walker and colleagues at the Sleep and Neuroimaging Lab at UC Berkeley, who found that a reduction in REM sleep (or less "dreaming") influences our ability to understand complex emotions in daily life – an essential feature of human social functioning.
>
> …
>
> Dreams seem to help us process emotions by encoding and constructing memories of them. What we see and experience in our dreams might not necessarily be real, but the emotions attached to these experiences certainly are. Our dream stories essentially try to strip the emotion out of a certain experience by creating a memory of it. This way, the emotion itself is no longer active. This mechanism fulfills an important role because when we don't process our emotions, especially negative ones, this increases personal worry and anxiety. In fact, severe REM sleep-deprivation is increasingly correlated to the development of mental disorders. In short, dreams help regulate traffic on that fragile bridge which connects our experiences with our emotions and memories.

Many people have written articles about possible meanings of one's dreams. Andrew Weils is author of the article, Why Dreams Are Vital to Emotional Health (Weils, 2/4/2012). Quoting from the article.

> While sleep is clearly vital to emotional well-being, what is it, exactly, about sleep that is so necessary? As it turns out, mood disorders are strongly linked to abnormal patterns of dreaming.
>
> …
>
> This is important information because many medications used to help people sleep also suppress dreaming. These drugs have become some of the most widely used in our society. Many antidepressant drugs suppress dreaming as well.
>
> …
>
> I think mainstream research tends to discount the value of dreaming because the experience is utterly subjective. Dreaming is a phenomenon of purely individual consciousness, and consequently impossible to thoroughly deconstruct by a community of researchers. But dreaming matters.
>
> If you dislike or even fear dreaming because the emotional content of your dreams tends to be negative, keep in mind that "bad dreams" may serve a vital function. Consider Dr. Naiman's view that dreaming is "a kind of psychological yoga," that contributes to emotional wellness. He says that dreams "in the first part of the night appear to process and diffuse residual negative emotion from the waking day; dreams later in the night then integrate this material into one's sense of self."

Lucid Dreaming

Lucid dreaming has received considerable attention in recent years. Quoting from the Wikipedia:

> A lucid dream is any dream in which one is aware that one is dreaming. In relation to this phenomenon, Greek philosopher Aristotle observed: "often when one is asleep, there is something in consciousness which declares that what then presents itself is but a dream".
>
> …
>
> It has been suggested that sufferers of nightmares could benefit from the ability to be aware they are indeed dreaming. A pilot study was performed in 2006 that showed that lucid dreaming therapy treatment was successful in reducing nightmare frequency. This treatment consisted of exposure to the idea, mastery of the technique, and lucidity exercises. It was not clear what aspects of the treatment were responsible for the success of overcoming nightmares, though the treatment as a whole was successful.

The Lucidity Institute is a small, internet-based research organization. Quoting from the website:

> …founded and directed by Dr. LaBerge. Its goals are to make lucid dreaming known to the public and accessible to anyone interested, to support research on lucid dreaming and other states of consciousness, and to study potential applications of lucid dreaming.
>
> …

> Lucidity usually begins in the midst of a dream when the dreamer realizes that the experience is not occurring in physical reality, but is a dream. Often this realization is triggered by the dreamer noticing some impossible or unlikely occurrence in the dream, such as flying or meeting the deceased. Sometimes people become lucid without noticing any particular clue in the dream; they just suddenly realize they are in a dream. A minority of lucid dreams (according to the research of LaBerge and colleagues, about 10 percent) are the result of returning to REM (dreaming) sleep directly from an awakening with unbroken reflective consciousness.

Many people, including your author, enjoy waking up and trying to remember their dreams. Sometimes they make a little sense to me, but often I can't relate them to things currently going on in my life.

Free Will and Education

My 6/25/2015 Google search of the term *free will* produced over 17 million results. Quoting from the Internet Encyclopedia of Philosophy:

> Most of us are certain that we have free will, though what exactly this amounts to is much less certain. According to David Hume, the question of the nature of free will is "the most contentious question of metaphysics." If this is correct, then figuring out what free will is will be no small task indeed. Minimally, to say that an agent has free will is to say that the agent has the capacity to choose his or her course of action.

Is the existence or non-existence of free will in humans a researchable question? Think about that for a minute. Is this a scientific question or a philosophical question. What do you believe would constitute good, solid, irrefutable evidence that free will exists or free will does not exist?

Kerri Smith's article, Neuroscience vs Philosophy: Taking Aim at Free Will, addresses the free will question (Smith, 8/31/2011). The article discusses research that measured brain activity well in advance of a person taking an action and becoming consciously aware of taking the action. The researchers concluded that the brain makes a decision at a subconscious level and then initiates action. Thus, they argue, the person's conscious "will" does not determine the action to be taken.

Quoting from the article:

> In 2007, Haynes, a neuroscientist at the Bernstein Center for Computational Neuroscience in Berlin, put people into a brain scanner in which a display screen flashed a succession of random letters. He told them to press a button with either their right or left index fingers whenever they felt the urge, and to remember the letter that was showing on the screen when they made the decision. The experiment used functional magnetic resonance imaging (fMRI) to reveal brain activity in real time as the volunteers chose to use their right or left hands. The results were quite a surprise.
>
> "The first thought we had was 'we have to check if this is real'," says Haynes. "We came up with more sanity checks than I've ever seen in any other study before."
>
> The conscious decision to push the button was made about a second before the actual act, but **the team discovered that a pattern of brain activity seemed to predict that decision by as many as seven seconds. Long before the subjects were even aware of**

> **making a choice, it seems, their brains had already decided.** [Bold added for emphasis.]

As might be expected, Haynes' research has stirred up a lot of discussion and the need for further research. Free will and consciousness are closely related topics. Earlier in this chapter we shared a little information from John Searle (Searle, July, 2013). He argues that consciousness is not an illusion. That is, we have consciousness and free will.

Continuing to quote from Kerri Smith's article:

> This month, a raft of projects will get under way as part of Big Questions in Free Will, a four-year, US$4.4 million programme funded by the John Templeton Foundation in West Conshohocken, Pennsylvania, which supports research bridging theology, philosophy and natural science. Some say that, with refined experiments, neuroscience could help researchers to identify the physical processes underlying conscious intention and to better understand the brain activity that precedes it. And if unconscious brain activity could be found to predict decisions perfectly, the work really could rattle the notion of free will. "It's possible that what are now correlations could at some point become causal connections between brain mechanisms and behaviours," says Glannon. "If that were the case, then it would threaten free will, on any definition by any philosopher."

Hypnosis and Education

Hypnosis is certainly not a new area of study, nor are its possible uses in education and other areas. The use of hypnosis has experienced considerable success in helping to deal with "bad" habits such as smoking, over-eating, and alcoholism. While such uses might be considered educational, this section focuses on learning and education in more traditional definitions of these terms.

There is considerable literature on the uses of hypnotism as an aid to learning. For example, my 6/28/2015 Google search of the term *hypnosis and learning* produced over 1.5 million results, while a search of the term *hypnosis and education* produced over 5 million results.

Ralph Alan Dale's paper, Hypnosis and Education, explores some possible educational uses of hypnosis (Dale, 1972). Quoting the abstract of this paper:

> Hypnosis is a state of mind which manifests a high degree of suggestibility. Advertising, political campaigning, and religious contemplation are all areas in which hypnotism is employed, usually without knowledge on the part of either the "hypnotist" or the subject. Because of its association with entertainment, magic, manipulation, and danger, hypnosis and suggestion have not yet been accepted or practiced in educational institutions even thought the evidence is clear that they offer the promise of immeasurable reward for education. **Nine possible uses of hypnosis and suggestion in education are** a) to reinforce positive habits and relinquish negative ones, b) to expand consciousness by increasing sensory and sensual response, c) to improve concentration, d) to aid memory, e) to increase motivation, f) to diminish "mental blocks," g) to reduce anxiety, h) to encourage original thinking, and i) to develop self-confidence. These nine uses of hypnosis and suggestion in education are, for the most part, still confined to theory and the research laboratory. Educational institutions have not yet availed themselves of the benefits that can be derived from the use of these techniques. [Bold added for emphasis.]

Remember, this is a 1972 paper. It illustrates that there was already considerable education knowledge about and use of hypnosis by that date. Quoting again from Dale:

> This article, then, does not presume to suggest the introduction of hypnosis to education. Hypnotic techniques have been employed throughout the history of education. Rather it is an appeal to explore the fullest uses of hypnotism, **particularly self-hypnotism,** [discussed later in this section] and to use it consciously and scientifically for the benefit of the student, the teacher, and the educational process itself. [Bold added for emphasis.]

Michael A. Rousell has written extensively about hypnosis in education. In his article, Understanding and Mastering Complexity: Spontaneously Clarifying Complexity, Rousell notes that the susceptibility created through hypnosis also exists in other settings. Quoting from his article (Rousell, July, 2013):

> My graduate program led me to hypnotic susceptibility as a major factor. My studies concluded that the conditions for hypnosis are regularly and substantially present in events such as those experienced by Cathy. [An example of a quick and profound change in Cathy's self-image is discussed in the article.] I thus needed to generate a thorough cognitive and neurological model to explain how and why these spontaneous transformative events take place. As indicated above, hypnosis was my initial explanatory model but it proved unsatisfactory because teachers don't really hypnotize their students in the traditional sense. Importantly though, I discovered that all of us experience natural spikes in susceptibility to suggestion that are similar to the heightened suggestibility induced in hypnosis. During these moments, we may profoundly change a mindset that in turn generates a dramatic shift in a belief. This is what happened to Cathy. Current models better explain how and why these events occur.

Hypnosis and Learning a Second Language

My 6/25/2015 Google search of the term *research on learning a language through hypnosis* produced nearly 3 million results. Many of the websites make claims about the effectiveness of using hypnotism in learning a second language, and many sell products they claim will greatly speed up the learning process. Interestingly, however, I was not able to find what I would consider to be "good" research to back their claims.

The American Association for Higher Education and Accreditation has published an extensive article, The AAHEA Report On Language Learning Through Hypnosis (AAHEA, 5/23/2015). Quoting from the website:

> Regarding the use of hypnosis to learn English, French or other languages, hypnosis is **often dubiously marketed** as a method of super-learning that induces a sleep-receptive state, which allows one to acquire knowledge both consciously and unconsciously. It is also often associated with hypnopaedia, a term used by the writer Aldous Huxley in his fantasy novel "A Brave New World," which is the hypothetical learning process that occurs during sleep, and that has been used to sell dubious courses to learn English while sleeping.
>
> In studies focusing on improving student learning, hypnosis has been used successfully to reduce anxiety about exams and to improve the academic performance of college students as well as children with learning difficulties. Nevertheless, the evidence is inconclusive due to methodological problems in the few studies that have been done on this topic.

> **However, the existing empirical research indicates that hypnosis does not enhance memory and, therefore, has no effect on learning languages.** [Bold added for emphasis.]

Self-Hypnosis

Many years ago I attended a workshop on hypnosis that taught rudiments of self-hypnosis. The ideas resonated with me, so I read a book on the topic and began to practice self-hypnosis as an aid to going to sleep at night and also as an aid to sleeping on long airplane flights. I was pleased with the results I achieved.

Emmett Miller is the author of What is Self-Hypnosis? (Miller, n.d.). Quoting from the beginning of his article:

> To understand how to use self-hypnosis, it will be easier to first examine "hypnosis" itself.
>
> Hypnosis: noun – A procedure in which suggestions (from the "operator," "hypnotist," or "guide") are given (to a subject) during a state of focused awareness.
>
> In other words, a hypnotic process is underway any time a person's attention is focused and possibilities are offered for their consideration.

This focused awareness can be achieved by one's self (self-hypnosis), by an outside agent, or by a combination of the two. Continuing to quote from Miller's article:

> What we are saying is that any experience that takes you into a relaxed or inspired state of mind by guiding your focused attention [brings you into] a hypnotic state, no matter what people may call it. By this definition, then, we can see quickly how television, PR agencies, political propaganda, religions, and advertising regularly make use of hypnotic processes. And obviously, it can, like any other powerful tool, be put to bad use as well as good use.

There are many definitions of self-hypnosis. For example, consider Mark Tyrrell's website where he explores What's the Difference Between Meditation and Hypnosis? (Tyrrell, 2015). Quoting from his website:

> People will often 'sell' hypnosis as just a 'state of deep relaxation'. This doesn't really make much sense, though. Hypnosis can be relaxed (and this is often how we use it therapeutically), but really it's any state of mind that makes us:
>
> • More disassociated.
>
> • More focused.
>
> • More suggestible.
>
> When people are experiencing a horribly traumatic experience, they become infinitely more suggestible. I've worked with people who were so traumatized that, even years later, they still respond to environmental 'post-hypnotic suggestions' (just from a 30-second traumatic experience) which take them right back to the original trauma. For instance, a war-weary veteran whose heart pounds every time he hears a car backfiring, or a driver who feels anxious whenever she passes the corner where she had that accident. This is pure hypnotic phenomenon, but not relaxation at all.

Sleep Learning and Education

My 7/10/2015 Google search of the term *sleep learning* produced over 17 million results. Quoting from the Wikipedia:

> Sleep-learning (also known as sleep-teaching, hypnopædia, or hypnopedia) is an attempt to convey information to a sleeping person, typically by playing a sound recording to them while they sleep. Research on this has been inconclusive. Some studies have largely discredited the technique's effectiveness, while others have found that the brain indeed reacts to stimuli and processes them while we are asleep.

Alduous Huxley's 1932 *Brave New World* novel incorporated the idea of sleep-teaching to brainwash people. For many years after that, a great many people believed that sleep-learning was possible, and that people could learn in their sleep by use of a recording device repeatedly playing what a person wanted to learn.

Megan Scudellari discusses sleep learning in her article, Why Learning in Your Sleep Is an Idea that's Reawakening (Scudellari, 6/11/2015). She notes that research done in 1951 suggested that sleep -earning works, while a 1955 study suggested that it did not work.

More recent research is providing evidence that sleep-learning does occur. Quoting from Scudellari's article:

> These days, we know far more about what goes on in our brains during sleep. "Up until a decade ago, most people thought not much was happening," says Sid Kouider, a cognitive neuroscientist at the École Normale Supérieure in Paris, France. Then, using EEG, researchers discovered that the brain doesn't shut off. Parts of it are surprisingly active even when we are unconscious. The sleeping brain appears to review and store memories, replaying moments in the day to preserve important information.

The article cites several research studies. For example:

> …Ken Paller, director of the cognitive neuroscience program at Northwestern University in Illinois…wanted to find out whether the same results could be achieved using sounds instead of smells. His volunteers learned the locations on a screen of 50 images, each paired with a specific sound, such as a meow for a cat and a whistle for a kettle. Then the participants took a nap, during which Paller's team quietly played half of the sounds to them. Upon waking, they better recalled the locations of objects whose sounds had been played while they slept, than those for which the associated sounds hadn't been played.

Here is another quote from Scudellari's article:

> It was becoming clear that memories can be influenced during sleep by external cues. In 2011, researchers in Born's lab made another discovery. Volunteers who learned a set of word pairs believing they would be tested the next morning performed better than those who weren't informed of the test or who were informed but didn't sleep. This suggested that the mere expectation that a memory will be important in future is enough to incite the sleeping brain to replay and strengthen it.

Research has also been done to determine whether instruction given to a sleeping person can help the person to stop smoking or to help cure a phobia. In both cases, positive results have been obtained. However, researchers are very cautious about these tentative findings and suggest that much more research is needed.

Meditation and Education

Hypnosis and meditation may be somewhat related. One might think of meditation as a type of self-hypnosis. However, a number of researchers and practitioners consider meditation and self-hypnosis to be quite different practices.

My 6/7/2015 Google search of the term *meditation and education* produced over 59 million results. A search of the term *meditation and educational research* produced over 22 million results. Quoting from the Wikipedia:

> Meditation is a practice in which an individual trains the mind or induces a mode of consciousness, either to realize some benefit or for the mind to simply acknowledge its content without becoming identified with that content, or as an end in itself.
>
> The term meditation refers to a broad variety of practices that includes techniques designed to promote relaxation, build internal energy or life force (qi, ki, prana, etc.) and develop compassion, love, patience, generosity and forgiveness. A particularly ambitious form of meditation aims at effortlessly sustained single-pointed concentration meant to enable its practitioner to enjoy an indestructible sense of well-being while engaging in any life activity.

Amanda Machado discusses experimenting with meditation in schools in her article, Should Schools Teach Kids to Meditate? (Machado, 1/27/2014). Quoting from the article:

> Harvard's Center for the Developing Child defines toxic stress as “severe, uncontrollable, chronic adversity” and explains that it can disrupt the architecture of the developing brain, often impeding academic learning and creating long-term physical- and mental-health problems.
>
> With almost half of current public school students considered low-income, the issue of “toxic stress” affecting young students has become more relevant.

Many students find that their lives are quite stressful. Some find this stress caries over into school, and they and other students find school to be stressful. Continuing to quote from Machado:

> As more research discovers the true effectiveness of these kids of programs, I at least take comfort in the fact that my students had the rare opportunity of learning the importance of mental health and character-building at such a young age. All students could benefit from learning these things early but with students whose backgrounds at times already place them at a disadvantage, these kinds of programs become even more justified. Every student should have access to skills necessary for confronting the anxiety of everyday life. As Tracy wrote to me: "We all deserve peace, and a calm mind."

Emily Campbell explores the relationship between mindfulness and meditation in her article, Research Round-up: Mindfulness in Schools (Campbell, 10/10/2013). Quoting from her article:

> The last decade has seen a huge spike in secular applications of mindfulness, the practice of focusing our attention on our thoughts, feelings, and environment in the present moment. While the first wave of mindfulness-based programs were for adults, more recent efforts have targeted the well-being of children and adolescents; as a result, mindfulness programs in schools are becoming more and more widespread.

> But until recently, "enthusiasm for promoting such practices [outweighed] the current evidence supporting them," to quote a 2012 review of the research on mindfulness practices with children and youth. That has changed in the past year with a spate of new studies: Researchers have been aggressively testing the effectiveness of school-based mindfulness programs, and they are starting to publish their results.

Campbell's article provides brief summaries of several research studies:

> [One study focused on] the curriculum of the Oakland-based Mindful Schools program, which serves low-income, ethnic-minority elementary school students. The Mindful Schools curriculum lasts five weeks, with three sessions per week, and focuses on mindfulness practices that help children pay attention, build empathy and self-awareness, improve self-control, and reduce stress. More than 400 students were evaluated in total in this study.
>
> *What did they find?*
>
> Immediately after the program ended, student behavior improved significantly in all four areas measured—paying attention, self-control, classroom participation, and respect for others—and these gains were maintained seven weeks later.

Body Over Mind, and Vice Versa

My 6/24/2015 Google search of the term *body over mind* produced about 183 million results. The majority of these explore the idea of mind over body—for example, in athletic events such as running. Quoting from Rational Wiki:

> The phrase "mind over body" represents the concept that the mind, through exercise or other methods, can be utilized to allow the body to defy its own limits. There are some sensible interpretations of this, but the concept also has its fair share of woo.
>
> …
>
> The most well-received explanation for the mind over body argument is the release of adrenalin into the body, which does increase strength and endurance.

Many researchers in the mind/body area argue that the mind and the body are one. See, for example, Jamie Hale's article, Is It Really Mind Over Matter? The Mind and Body are One (Hale, 2011). Quoting from this article:

> You have probably heard the phrase mind over matter, which implies the mind and matter are separable. Or maybe you have heard it's all in your head, or it's mental. Both of these phrases imply the separation of mind and brain (or body).
>
> So to explore this issue, I'd like to share some videos that discuss the unity of mind-body. They can help us better understand how inseparable the mind and brain (body) really are.

The article then continues with several short videos. In a 2:28 video, Yale psychologist Paul Bloom says, "The mind is a product of the brain. The mind is what the brain does." Temple Grandin gives a personal example about the functioning of her own (autistic) brain, and how medication helped her.

Quoting from the Wikipedia:

> In philosophy of mind, dualism is a view about the relationship between mind and matter which claims that mind and matter are two ontologically separate categories. Mind-body dualism claims that neither the mind nor matter can be reduced to each other in any way. Western dualist philosophical traditions (as exemplified by Descartes) equate mind with the conscious self and theorize on consciousness on the basis of mind/body dualism. By contrast, some Eastern philosophies draw a metaphysical line between consciousness and matter — where matter includes both body and mind.

An ongoing debate about dualism pits those who believe the mind and brain are one against those who think the body and soul are distinct. This is the focus of a debate between Steven Rose and Steven Pinker (Pinker & Rose, 1/21/2015).

Quoting Steven Pinker

> The mind is a system of organs of computation, designed by natural selection to solve the kinds of problems our ancestors faced in their foraging way of life, in particular, understanding and outmaneuvering objects, animals, plants, and other people. The summary can be unpacked into several claims. The mind is what the brain does; specifically, the brain processes information, and thinking is a kind of computation. The mind is organized into modules or mental organs, each with a specialized design that makes it an expert in one arena of interaction with the world. The modules' basic logic is specified by our genetic program. Their operation was shaped by natural selection to solve the problems of the hunting and gathering life led by our ancestors in most of our evolutionary history. The various problems for our ancestors were subtasks of one big problem for their genes, maximizing the number of copies that made it into the next generation.

Quoting Steven Rose

> (My task is to) offer an alternative vision of living systems, a vision which recognizes the power and role of genes without subscribing to genetic determinism, and which recaptures an understanding of living organisms and their trajectories through time and space as lying at the centre of biology. It is these trajectories that I call lifelines. Far from being determined, or needing to invoke some non-material concept of free will to help us escape the determinist trap, it is in the nature of living systems to be radically indeterminate, to continually construct their-our-own futures, albeit in circumstances not of our own choosing.

Amy Cuddy is an associate professor in the Harvard Business College. Her *TED Talks,* Body Language Shapes Who You Are, has had over 26.5 million hits as of 6/18/2015 (Cuddy, June, 2012). Her thesis is quite simple. Your body language can change your brain chemistry, and thus the way your brain functions.

Her research and the research of others has explored how changing one's body language to imitate a person with power actually raises one's testosterone and decreases one's level of cortisol. You feel more powerful and you are less stressed! In brief summary, her research indicated that *faking it* can lead to a permanent change—which she calls *making it.*

Quoting from the introduction of Cuddy's *TED Talks:*

> So my main collaborator Dana Carney, who's at Berkeley, and I really wanted to know, **can you fake it till you make it?** Like, can you do this just for a little while and actually

> experience a behavioral outcome that makes you seem more powerful? So we know that our nonverbals govern how other people think and feel about us. There's a lot of evidence. But our question really was, do our nonverbals govern how we think and feel about ourselves?
>
> There's some evidence that they do.
>
> …
>
> So the second question really was, you know, so we know that our minds change our bodies, but is it also true that our bodies change our minds? And when I say minds, in the case of the powerful, what am I talking about? So I'm talking about thoughts and feelings and the sort of physiological things that make up our thoughts and feelings, and in my case, that's hormones. I look at hormones. So what do the minds of the powerful versus the powerless look like? So powerful people tend to be, not surprisingly, more assertive and more confident, more optimistic. They actually feel they're going to win even at games of chance. They also tend to be able to think more abstractly. So there are a lot of differences. They take more risks. There are a lot of differences between powerful and powerless people. Physiologically, there also are differences on two key hormones: testosterone, which is the dominance hormone, and cortisol, which is the stress hormone. So what we find is that high-power alpha males in primate hierarchies have high testosterone and low cortisol, and powerful and effective leaders also have high testosterone and low cortisol. So what does that mean? **When you think about power, people tended to think only about testosterone, because that was about dominance. But really, power is also about how you react to stress.** So do you want the high-power leader that's dominant, high on testosterone, but really stress reactive? Probably not, right? You want the person who's powerful and assertive and dominant, but not very stress reactive, the person who's laid back. [Bold added for emphasis.]

Final Remarks

Brain science is a very large and rapidly growing area of study. Our steadily improving brain-scanning equipment, more powerful computers, better brain-computer interfaces, and improving understanding of the biology of the human genome and individual cells—all are fueling progress in this area.

As with any healthy area of scientific research, each line of successful (or unsuccessful) research progress leads to more questions. This is one of the fundamental ideas from the fields of science, technology, engineering, and mathematics (STEM). Here are two *TED Talks* that provide valuable advice to teachers and students in the STEM areas.

E.O. Wilson: Advice to Young Scientists

Edward Osborne Wilson is a Nobel Prize winning biologist. In his *TED Talks* he gives advice to students interested in research careers (Wilson, April, 2012). Quoting from his talk:

> Knowledge in medical science and science overall is doubling every 15 to 20 years. Technology is increasing at a comparable rate. Between them, the two already pervade, as most of you here seated realize, every dimension of human life.
>
> So swift is the velocity of the techno-scientific revolution, so startling in its countless twists and turns, that no one can predict its outcome even a decade from the present moment.

> There will come a time, of course, when the exponential growth of discovery and knowledge, which actually began in the 1600s, has to peak and level off, but that's not going to matter to you. **The revolution is going to continue for at least several more decades. It'll render the human condition radically different from what it is today.** Traditional fields of study are going to continue to grow and in so doing, inevitably they will meet and create new disciplines. [Bold added for emphasis.]

I find it hard to imagine a doubling and then a redoubling of our total knowledge in brain science and in other areas of science and technology. What an opportunity for researchers, and what a challenge to people who will have to adjust to such a pace of change. **The message to our educational system is to prepare students for a lifetime of change and a need for lifelong education.**

Stuart Firestein: The Pursuit of Ignorance

Stuart Firestein is a leading cognitive neuroscientist and teacher. He has created a unique course focusing on a combination of what we know and what we do not know (Firestein, 9/24/2013). Quoting from his *TED Talks*:

> There is an ancient proverb that says it's very difficult to find a black cat in a dark room, especially when there is no cat. I find this a particularly apt description of science and how science works—bumbling around in a dark room, bumping into things, trying to figure out what shape this might be, what that might be, there are reports of a cat somewhere around, they may not be reliable, they may be, and so forth and so on.
>
> Now I know this is different than the way most people think about science. Science, we generally are told, is a very well-ordered mechanism for understanding the world, for gaining facts, for gaining data, that it's rule-based, that scientists use this thing called the scientific method and we've been doing this for 14 generations or so now, and the scientific method is a set of rules for getting hard, cold facts out of the data.

Firestein laments the thickness and weight (more than twice the weight of a human brain) of the textbook he uses in a lower division course he teaches. He explains that such courses now teach science as if we teachers thoroughly understand what we are presenting, and that science consists of answers. This leads into his thoughts on our high level of ignorance.

> I mean … a kind of ignorance that comes from a communal gap in our knowledge, something that's just not there to be known or isn't known well enough yet or we can't make predictions from, the kind of ignorance that's maybe best summed up in a statement by James Clerk Maxwell, perhaps the greatest physicist between Newton and Einstein, who said, **"Thoroughly conscious ignorance is the prelude to every real advance in science." I think it's a wonderful idea: thoroughly conscious ignorance.**
>
> So that's the kind of ignorance that I want to talk about today, but of course the first thing we have to clear up is what are we going to do with all those facts? So it is true that science piles up at an alarming rate. We all have this sense that science is tshis mountain of facts, this accumulation model of science, as many have called it, and it seems impregnable, it seems impossible. How can you ever know all of this? And indeed, the scientific literature grows at an alarming rate. In 2006, there were 1.3 million papers published. There's about a two-and-a-half-percent yearly growth rate, and so last year we saw over one-and-a-half-million papers being published. Divide that by the number of

> minutes in a year, and you wind up with three new papers per minute. So I've been up here a little over 10 minutes, I've already lost three papers. I have to get out of here actually. I have to go read. [Bold added for emphasis.]

The message is that there is much more to getting a good education than just learning the accumulated "facts."

Think about some of the "facts" that have been presented in the current chapter. Then pose some questions to yourself about what is missing. While the "facts" present a façade of knowledge and understanding, they leave far more questions unanswered than questions answered.

You and Your Students

Think back over this chapter. Of the six major topics—consciousness, dreaming, free will, hypnosis, sleep learning, and meditation—which one interested you the most? Why? Similarly, which seemed of least interest to you, and why?

For the topic that you find most interesting, what do you think students should be learning about this topic? This is a very hard question, and it is representative of the educational questions that arise with continued progress in each area of research in science, technology, engineering, and mathematics.

This chapter provides teachers and their students with three golden opportunities to learn together.

1. What Is Going On in Your Brain?

Every student is apt to find some, if not most, of the content of this chapter personally relevant and interesting. For example:

- What do dreams mean and what can I learn from them?
- What about free will? Am I responsible for what I do—even when I become so angry that I "just lose it"?
- Can I be hypnotized? Can I sort of hypnotize myself?
- What can I gain through learning to meditate?

Here is a metacognition activity that you might use to set your students thinking about their brains. Say to your students in a calm, soothing voice:

> Close your eyes and take several slow, deep breaths. Think about your breathing as you continue to take slow, deep breaths.
>
> Now make a make a picture in your mind of an animal. Imagine its size, color, where it lives, and what it does. Mentally talk to yourself, describing your animal.
>
> Now open your eyes and resume normal breathing. Think about what has gone on in your brain. Each person in the class formed a unique picture and description of the picture. Where is that picture and description? Think about how powerful and capable your brain is to be able to create and store a picture. Share your experience and insights with a group of two or three other students.

2. You and Your Students Learning Together

Topics in this chapter are ones that allow you to learn with your students. That is, both you and your students have unique and different insights into the topics. For example, take the topic of consciousness.

Reflect on your current understanding of what it means for a human brain to have consciousness. Have your students do the same reflection. Then, do both small group and whole class sharing of your students' insights and your own.

Explore with your students what happens to your consciousness when you fall asleep. Is dreaming a state somewhere between consciousness and unconsciousness? After reading this chapter, you know that everyone dreams and that some of us are better at remembering our dreams than are others. Many people like to talk about their dreams, and some people keep dream diaries.

It can be interesting to interpret possible meanings of your dreams, or to try to relate your dreams to things going on in your conscious life when you are awake. Perhaps we can learn something about our conscious selves through what we do remember of our dreams. It may be interesting for you and your students to try.

3. Each of Us Is Unique

We know that each person is quite a bit different from every other person. What can you learn about yourself by analyzing (thinking about) your own thinking? What is there about **you** that makes you uniquely you?

What can you learn about someone else by listening to them, viewing their actions, and trying to figure out what is going on in their brains? What makes your best friend into a unique person, and what characteristics make this person become your best friend?

Consciousness and unconsciousness, together with an "in between" state we call dreaming, are important parts of our lives. We all experience these three states, and each of us has unique experiences that we can reflect on and share. In doing so, we learn more about ourselves. In listening, we learn about others and how we are in many ways both somewhat the same and somewhat different from them.

References and Resources for Chapter 7

AAHEA (5/23/2015). The AAHEA report on language learning through hypnosis. *American Association for Higher Education and Accreditation.* Retrieved 6/28/2015 from http://www.aahea.net/the-aahea-report-on-language-learning-through-hypnosis/. Quoting from the report:

> In conclusion, the study and learning of a language is a complex process that involves implementing numerous resources, and there is no scientific evidence that hypnosis facilitates rapid and effortless learning of a language.

Campbell, E. (10/10/2013). Research round-up: Mindfulness in schools. *Greater Good in Action (Berkeley)*. Retrieved 6/7/2015 from http://greatergood.berkeley.edu/article/item/research_round_up_school_based_mindfulness_programs. Quoting from the website:

> Research is trying to keep pace with the explosion of interest in school-based mindfulness programs. Here's a round-up of four new studies at the frontier.

Cuddy, A. (June, 2012). Body language shapes who you are. (Video, 21:02.) *TED Talks.* Retrieved 6/18/2015 from http://www.ted.com/talks/amy_cuddy_your_body_language_shapes_who_you_are?language=en. Quoting from the website:

> Body language affects how others see us, but it may also change how we see ourselves. Social psychologist Amy Cuddy shows how "power posing" — standing in a posture of confidence, even when we don't feel confident — **can affect testosterone and cortisol levels in the brain**, and might even have an impact on our chances for success. [Bold added for emphasis.]

Dale, R.A. (1972). Hypnosis and education. Retrieved 6/25/2015 from http://files.eric.ed.gov/fulltext/ED087710.pdf.

This article points out that teachers and other communicators frequently make use of hypnosis-like ideas and procedures. It provides interesting historical information and some of the research up to 1972.

Damasio, A. (March, 2011). The quest to understand consciousness. (Video, 18:42.) *TED Talks*. Retrieved 6/25/2015 from http://www.ted.com/talks/antonio_damasio_the_quest_to_understand_consciousness?language=en. Quoting from the website:

> Every morning we wake up and regain consciousness — that is a marvelous fact — but what exactly is it that we regain? Neuroscientist Antonio Damasio uses this simple question to give us a glimpse into how our brains create our sense of self.

Dennett, D. (February, 2003). The illusion of consciousness. (Video, 21:48.) *TED Talks.* Retrieved 6/25/2015 from http://www.ted.com/talks/dan_dennett_on_our_consciousness?language=en. Quoting from the website:

> Philosopher Dan Dennett makes a compelling argument that not only don't we understand our own consciousness, but that half the time our brains are actively fooling us. [He] argues that human consciousness and free will are the result of physical processes.

Firestein, S. (9/24/2013). The pursuit of ignorance with Stuart Firestein. (Video, 18:33.) *TED Talks*. Retrieved 7/5/201 from http://tedtalkspsychology.com/the-pursuit-of-ignorance-with-stuart-firestein/. Quoting from the website:

> One of the secrets that Firestein shares is that scientific research is often a hit or miss affair with some use of the scientific method combined with a good deal of luck. You might be surprised to learn that as potential scientists, we should value "high quality ignorance" as well as perceived knowledge.

Hale, J. (2011). Is it really mind over matter? The mind and body are one. *World of Psychology.* Retrieved 6/18/2015 from http://psychcentral.com/blog/archives/2011/08/24/is-it-really-mind-over-matter-the-mind-and-body-are-one/. Quoting from the website:

> There is absolutely no reason to be confident in the belief of a separable mind and body, mental and physical, while there are many reasons to not be confident in the mind and body dichotomy.

IASD (n.d.). Education. International Association for the Study of Dreams. Retrieved 6/19/2015 from http://www.asdreams.org. Quoting from the website:

> Our purposes are to promote an awareness and appreciation of dreams in both professional and public arenas; to encourage research into the nature, function, and significance of dreaming; to advance the application of the study of dreams; and to provide a forum for the eclectic and interdisciplinary exchange of ideas and information.

Kaku, M. (2014). *The future of the mind: The scientific quest to understand, enhance, and empower the mind.* New York: Random House.

Theoretical physicist Michio Kaku details some developments in computer technology, artificial intelligence, and medicine that are poised to happen over the next hundred years. He considers how these inventions will affect the world economy.

Linden, S. (7/26/2011). The science behind dreaming. *Scientific American.* Retrieved 6/19/2015 from http://www.scientificamerican.com/article/the-science-behind-dreaming/. Quoting from the article:

> While there has always been a great interest in the interpretation of human dreams, it wasn't until the end of the nineteenth century that Sigmund Freud and Carl Jung put forth some of the most widely-known modern theories of dreaming.

Lipton, B.H. (2001). Insight into cellular consciousness. *Bridges* (ISSEEEM.org). Retrieved 6/25/20015 from https://www.brucelipton.com/resource/article/insight-cellular-consciousness.

This paper presents detailed information about the makeup of a single cell. It argues that a single-cell animal, such as the amoeba or paramecium, has a type of consciousness, and that human consciousness comes through the interaction of the cells in a human nervous system.

Machado, A. (1/27/2014). Should schools teach kids to meditate? *The Atlantic.* Retrieved 6/7/2015 from http://www.theatlantic.com/education/archive/2014/01/should-schools-teach-kids-to-meditate/283229/. Quoting from the article:

> Harvard's Center for the Developing Child defines toxic stress as "severe, uncontrollable, chronic adversity" and explains that it can disrupt the architecture of the developing brain, often impeding academic learning and creating long-term physical and mental-health problems.
>
> With almost half of current public school students considered low-income, the issue of "toxic stress" affecting young students has become more relevant.

Miller, E. (n.d.). What is self-hypnosis? *Learning Center.* Retrieved 6/25/2015 from http://drmiller.com/learning-center/selfhypnosis/.

Focus on the following suggestion for a short period of time and you likely will enter a self-induced light "trance" state.

Picture in your mind a relaxed, peaceful place or event from your past. Visualize and focus on this place or event.

NOVA (9/15/2012). What are dreams? (Video, 55:05.) *PBS.org.* Retrieved 6/19/2015 from https://www.youtube.com/watch?v=i539ynXmh-c.

This video presents a number of examples of dreams, information from and/or about people who have done research on dreams, and some insights from dream researchers.

NOVA (Multiple dates.) Body + brain. *PBS.org.* Retrieved 6/19/2015 from http://www.pbs.org/wgbh/nova/body/.

Includes 15 full episodes, 89 short videos, 39 articles, and a variety of other resources.

Pinker, S., & Rose, S. (1/21/2013). The two Steves–Pinker vs. Rose–a debate. Edge Foundation, Inc. Retrieved 6/24/2015 from http://www.edge.org/3rd_culture/pinker_rose/pinker_rose_p1.html. Quoting from the website:

> The Two Steves have serious disagreements. But whether it's Steve Pinker weighing forth on the notion that the "problems for our ancestors were subtasks of one big problem [survival] for their genes" or Steve Rose asserting that "it is in the nature of living systems to be radically indeterminate, to continually construct their-our-own futures," their debate, their disagreement sharpens and clarifies.

Rousell, M.A. (July, 2013). Understanding and mastering complexity: Spontaneously clarifying complexity. *IAE Newsletter.* Retrieved 7/5/2015 from http://i-a-e.org/newsletters/IAE-Newsletter-2013-118.html. Quoting from the article:

> As a young teacher, I wondered if many of my students were unwittingly acting out suggestions given to them by authority figures during natural moments of high suggestibility. Eureka! It's just like hypnosis.

Scudellari, M. (6/11/2015). Why learning in your sleep is an idea that's reawakening. *New Scientist.* Retrieved 7/10/2015 from http://www.newscientist.com/article/mg22630250.800-why-learning-in-your-sleep-is-an-idea-thats-reawakening.html. Quoting from the article:

> In Aldous Huxley's dystopian novel *Brave New World,* recorded voices whisper class prejudices into the ears of sleeping children, conditioning them for their future roles in society. Despite the evil ends that Huxley imagined, the appeal of getting something for nothing was irresistible to readers and, following the book's publication in 1932, there was a surge in interest in sleep learning.

Searle, J. (July, 2013). Our shared condition–consciousness. (Video, 14:59.) *TED Talks.* Retrieved 6/25/2015 from https://www.ted.com/talks/john_searle_our_shared_condition_consciousness?language=en. Quoting from the website:

> Philosopher John Searle lays out the case for studying human consciousness — and systematically shoots down some of the common objections to taking it seriously. As we learn more about the brain processes that cause awareness, accepting that consciousness is a biological phenomenon is an important first step.

Smith, K. (8/31/2011). Neuroscience vs philosophy: Taking aim at free will. *Nature.* Retrieved 6/25/2015 from http://www.nature.com/news/2011/110831/full/477023a.html. Quoting from the website:

Scientists think they can prove that free will is an illusion. Philosophers are urging them to think again. Substantial amounts of research are now being done on consciousness and free will.

Sylwester, R., & Moursund, D., eds. (June, 2013). *Consciousness and morality: Recent research developments.* Eugene, OR: Information Age Education. Download the PDF file from http://i-a-e.org/downloads/doc_download/251-consciousness-and-morality-recent-research-developments.html. Download the Microsoft Word file from http://i-a-e.org/downloads/doc_download/252-consciousness-and-morality-recent-research-developments.html. Quoting from the Preface to the book:

> Forty years after the discovery of DNA, Crick wrote a remarkable widely read book on cognition, *The Astonishing Hypothesis: The Scientific Search for the Soul* (1994). See http://en.wikipedia.org/wiki/The_Astonishing_Hypothesis. The book's basic point is that it's necessary to understand consciousness if we're ever going to truly understand how our brain can function both within and beyond genetics.

Tyrrell, M. (2015). What's the difference between meditation and hypnosis? *Uncommon Help.* Retrieved 6/25/2015 from http://www.uncommonhelp.me/articles/whats-the-difference-between-meditation-and-hypnosis/. Quoting from the website:

> Hypnosis, used purposefully, will generally have a very specific psychological (and therefore behavioral) aim.… Meditation may have, as a 'by-product', the effect of making us calmer day-to-day, but it's not usually used to stop someone smoking or to treat a specific phobia.

Weils, A. (2/4/2012. Why dreams are vital to emotional health. *Huffpost.* Retrieved 6/14/2015 from http://www.huffingtonpost.com/andrew-weil-md/dreams-depression_b_1273422.html. Quoting from the article:

> The bottom line: There is good reason to believe you must get sufficient sleep, and embrace rather than suppress your dreams, if you want to experience better moods.

Wilson, E.O. (April, 2012). Advice to young scientists. (Video, 14:56.) *TED Talks.* Retrieved 7/5/2015 from https://www.ted.com/talks/e_o_wilson_advice_to_young_scientists. Quoting from the website:

> "The world needs you, badly," begins celebrated biologist E.O. Wilson in his letter to a young scientist. Previewing his upcoming book, he gives advice collected from a lifetime of experience — reminding us that wonder and creativity are the center of the scientific life.

Chapter 8. Brain Disorders

> "Knowing is not enough. We must apply. Willingness is not enough. We must do." (Johann Wolfgang von Goethe; German writer and statesman; 1749-1832.)

An adult brain weights about three pounds, has the consistency of soft butter, and contains about 86 billion neurons. A neuron is a single cell consisting of a cell body, an axon, and a large number of dendrites. In total, there are approximately 1,000 trillion dendrites that form connections among the neurons. Try to picture in your mind a machine containing 1,000 trillion "wires" connecting its various parts. A million-billion connections. A brain is a very complex object!

A number of students have developmental disabilities such as dyslexia (a reading disability), dysgraphia (a writing disability), and dyscalculia (an arithmetic disability). All of these developmental disabilities affect a student's abilities to learn parts of the traditional school curriculum such as reading, writing, and arithmetic.

Here is an interesting question to ponder. Were the "disabilities" we call dyslexia, dysgraphia, and dyscalculia actually disabilities before written language was developed? Perhaps they made little or no difference—or made a positive contribution—to the survival and reproductive rates of people with these particular brain differences.

This chapter explores a variety of brain disorders.

fMRI and Other Tools for Studying the Inside of a Brain

It is only recently that technology has begun to produce tools allowing researchers to "see" the functioning of a brain. The first of these tools was fMRI (functional Magnetic Resonance Imaging). From its humble and fuzzy image-producing capabilities in the early 1990s, it has grown steadily in capability and use. A lecture on the history of fMRI is available at http://www.martinos.org/history-fMRI.

Nancy Kanwisher is a professor at MIT who uses fMRI to study the human brain. The site http://nancysbraintalks.mit.edu/#sthash.dhUwaBwB.dpuf contains short talks on the different scientific methods we can use to study the human mind and brain, and some of the things we have learned so far.

Quoting from Kanwisher's *TED Talks,* A Neural Portrait of the Human Mind (Kanwisher, March, 2014):

> Today I want to tell you about a project being carried out by scientists all over the world to paint a neural portrait of the human mind. And the central idea of this work is that the human mind and brain is not a single, general-purpose processor, but a collection of highly specialized components, each solving a different specific problem, and yet collectively making up who we are as human beings and thinkers.

Next, Kanwisher talks about a brain defect named face blindness (prosopagnosia) It is an inability to recognize people by their faces. Quoting from the Wikipedia:

> Prosopagnosia, also called face blindness, is a cognitive disorder of face perception where the ability to recognize faces is impaired, while other aspects of visual processing (e.g., object discrimination) and intellectual functioning (e.g., decision making) remain intact. The term originally referred to a condition following acute brain damage (acquired prosopagnosia), but a congenital or developmental form of the disorder also exists, which may affect up to 2.5% of the population.

I (David Moursund), have face blindness. I did not discover this until I read about it in a 2006 *Time* magazine article. Needless to say, it is a major handicap being a teacher working with a great many students, and not being able to learn to recognize them by their faces!

There are many free self-assessment tests for face blindness available on the Web. For example, see the article, Do You Have Troubles Recognizing Faces? Take a Test (*CBS News,* 8/5/2012).

The Prosopagnosia Research Center at Bournemouth University, UK provides a list of symptoms that are useful in identifying prosopagnosia in young children. The site provides advice to parents, teachers, and others who suspect a child may be face blind. As with many developmental disorders, early diagnosis allows early treatment and/or education to help one learn to cope with the disability.

Continuing to quote Kanwisher (Kanwisher, March, 2014):

> Prosopagnosia is one of many surprisingly specific mental deficits that can happen after brain damage. These syndromes collectively have suggested for a long time that the mind is divvied up into distinct components, but the effort to discover those components has jumped to warp speed with the invention of brain imaging technology, especially fMRI. So fMRI enables you to see internal anatomy at high resolution.

Kanwisher's talk identifies a number of other brain regions with quite specific purposes. Pointing to a blue-colored region in a diagram of the brain she says:

> This region responds when you think about what another person is thinking. So that may seem crazy, but actually, we humans do this all the time. You're doing this when you realize that your partner is going to be worried if you don't call home to say you're running late. I'm doing this with that region of my brain right now when I realize that you guys [her audience] are probably now wondering about all that gray, uncharted territory in the brain, and what's up with that?

Developmental Disorders: ADHD, Autism and Asperger's, Dyslexia, Dyscalculia, and Dysgraphia

Brain disorders can come from nature, nurture, or a combination of the two. Face blindness, described in the previous section, can come from nature—a miswiring of the brain. Or, it can come from nurture, such as brain damage to the facial recognition parts of a brain.

This section examines developmental disorders—disorders produced by miswiring in the brain. The electroencephalogram is a useful brain-scanning tool in this area of research and diagnosis. Quoting from the Mayo Clinic:

> An electroencephalogram (EEG) is a test that detects electrical activity in your brain using small, flat metal discs (electrodes) attached to your scalp. Your brain cells

> communicate via electrical impulses and are active all the time, even when you're asleep. This activity shows up as wavy lines on an EEG recording.
>
> An EEG is one of the main diagnostic tests for epilepsy. An EEG may also play a role in diagnosing other brain disorders.

Aditi Shankardass' *TED Talks* is titled, A Second Opinion On Developmental Disorders (Shankardass, November, 2009.) Quoting from her talk:

> It was while I was doing my Ph.D. on the neurological causes of dyslexia in children that I encountered a startling fact that I'd like to share with you all today. It is estimated that one in six children, that's one in six children, suffer from some developmental disorder. This is a disorder that retards mental development in the child and causes permanent mental impairments. Which means that each and every one of you here today knows at least one child that is suffering from a developmental disorder.
>
> …
>
> But here's what really perplexed me. Despite the fact that each and every one of these disorders originates in the brain, most of these disorders are diagnosed solely on the basis of observable behavior. But diagnosing a brain disorder without actually looking at the brain is analogous to treating a patient with a heart problem based on their physical symptoms, without even doing an ECG or a chest X-ray to look at the heart. It seemed so intuitive to me. To diagnose and treat a brain disorder accurately, it would be necessary to look at the brain directly. Looking at behavior alone can miss a vital piece of the puzzle and provide an incomplete, or even a misleading, picture of the child's problems. Yet, despite all the advances in medical technology, the diagnosis of brain disorders in one in six children still remained so limited.

Now, look back at the quote from Johann Wolfgang von Goethe at the beginning of this chapter. Based on the research of Shankardass and others, we have strong evidence that a significant percentage of children have a brain disorder, and that brain imaging is a very good way to identify these disorders. **However, such brain imaging is not yet commonplace in identifying brain disorders in children. I wonder why.**

My 7/13/2015 Google search on *percentage of U.S. children with brain disorders* produced over 59 million results. The literature certainly support's Shankerdass' estimate of 16 (or more) percent of children have brain disorders. The literature also suggests that the U.S. is not doing very well in identifying children with brain disorders and providing them with appropriate treatment.

Attention Deficit Hyperactivity Disorder (ADHD)

Quoting from the Mayo Clinic:

> Attention-deficit/hyperactivity disorder (ADHD) is a chronic condition that affects millions of children and often persists into adulthood. ADHD includes a combination of problems, such as difficulty sustaining attention, hyperactivity and impulsive behavior.
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> Children with ADHD also may struggle with low self-esteem, troubled relationships and poor performance in school. Symptoms sometimes lessen with age. However, some people never completely outgrow their ADHD symptoms. But they can learn strategies to be successful.

> This is particularly interesting in that it is a problem in schools, but perhaps a benefit in survival when people were hunter-gatherers. It has both nature and nurture causes. .

The number of children being diagnosed as ADHD is growing. Valerie Strauss discusses this phenomenon in her article, Why So Many Kids Can't Sit Still in School Today (Strauss, 7/8/2014). Quoting from the article:

> The Centers for Disease Control tells us that in recent years there has been a jump in the percentage of young people diagnosed with Attention Deficit and Hyperactivity Disorder, commonly known as ADHD: 7.8 percent in 2003 to 9.5 percent in 2007 and to 11 percent in 2011. The reasons for the rise are multiple, and include changes in diagnostic criteria, medication treatment and more awareness of the condition. In the following post, Angela Hanscom, a pediatric occupational therapist and the founder of TimberNook, a nature-based development program designed to foster creativity and independent play outdoors in New England, suggests yet **another reason more children are being diagnosed with ADHD, whether or not they really have it: the amount of time kids are forced to sit while they are in school.** [Bold added for emphasis.]

We know that ADHD comes from nature, nurture, and a combination of nature and nurture. David A. Sousa summarizes the research on ADHD in his *TEDx Talk,* ADHD—A Case for Over Diagnosis? (Sousa, 1/28/2013). The reported/estimated diagnosis of ADHD has more than doubled to nearly 18% of 4 to 17 year olds during the past decade. Sousa discusses a number of reasons why the diagnosis of ADHD is occurring more frequently and often is incorrect. The following list is adapted from Sousa's talk:

1. Caffeine taken before a test can improve cognitive performance. However, too much caffeine produces hyperactivity. Many students get way to much caffeine.
2. The artificial sweetener aspartame affects the growing brain and produces hyperactivity, and it is widely used in soft rinks and other foods.
3. Widely used food preservatives such as sodium benzoate and benzoic acid produce hyperactivity.
4. Some widely used food colorings product hyperactivity.
5. Sleep deprivation produces irritable and hyperactivity.
6. Stress produces cortisol and this produces hyperactivity.
7. Certain types of schooling produce and/or add to ADHD behavior. Student brains trained and used to searching out (needed/desired) information can have trouble with schools functioning in a stand and deliver mode of presenting information.

In addition, many students are not being taught and/or are not learning rules of behavior with other people, such as comfortably engaging in face-to-face conversations. Game-playing and computer-based social networking are often viewed by adults as a behavioral disorder.

Autism and Asperger's Syndrome

Quoting from the Wikipedia:

> Autism is a disorder of neural development characterized by impaired social interaction, by impaired verbal and non-verbal communication, and by restricted, repetitive or stereotyped behavior. The diagnostic criteria require that symptoms become apparent

> before a child is three years old. Autism affects information processing in the brain by altering how nerve cells and their synapses connect and organize; how this occurs is not well understood. It is one of three recognized disorders in the autism spectrum (ASDs), the other two being Asperger's syndrome, which lacks delays in cognitive development and language, and pervasive developmental disorder, not otherwise specified (commonly abbreviated as PDD-NOS), which is diagnosed when the full set of criteria for autism or Asperger syndrome are not met.

The history of our growing understanding of autism is quite interesting. Steve Silberman presents some of this history in his presentation, The Forgotten History of Autism (Silberman, March, 2015). This history goes back to 1943, when a child psychiatrist at Johns Hopkins Hospital named Leo Kanner published a paper describing eleven young patients who seemed to inhabit private worlds, ignoring the people around them, even their own parents. Quoting Silberman:

> Kanner was a smart guy, but a number of his theories didn't pan out. He classified autism as a form of infantile psychosis caused by cold and unaffectionate parents. These children, he said, had been kept neatly in a refrigerator that didn't defrost. At the same time, however, Kanner noticed that some of his young patients had special abilities that clustered in certain areas like music, math and memory. One boy in his clinic could distinguish between 18 symphonies before he turned two. When his mother put on one of his favorite records, he would correctly declare, "Beethoven!" But Kanner took a dim view of these abilities, claiming that the kids were just regurgitating things they'd heard their pompous parents say, desperate to earn their approval. As a result, autism became a source of shame and stigma for families, and two generations of autistic children were shipped off to institutions for their own good, becoming invisible to the world at large.
>
> Amazingly, it wasn't until the 1970s that researchers began to test Kanner's theory that autism was rare. Lorna Wing was a cognitive psychologist in London who thought that Kanner's theory of refrigerator parenting were "bloody stupid," as she told me. She and her husband John were warm and affectionate people, and they had a profoundly autistic daughter named Susie. Lorna and John knew how hard it was to raise a child like Susie without support services, special education, and the other resources that are out of reach without a diagnosis.

The research by Lora and John Wing uncovered a long lost (and little read) 1944 paper by Hans Asperger that presented a quite modern view of autism. Quoting again from Silberman's talk:

> Asperger's ideas about teaching children with learning differences were progressive even by contemporary standards. Mornings at his clinic began with exercise classes set to music, and the children put on plays on Sunday afternoons. **Instead of blaming parents for causing autism, Asperger framed it as a lifelong, polygenetic disability that requires compassionate forms of support and accommodations over the course of one's whole life.** Rather than treating the kids in his clinic like patients, Asperger called them his little professors, and enlisted their help in developing methods of education that were particularly suited to them. Crucially, **Asperger viewed autism as a diverse continuum that spans an astonishing range of giftedness and disability.** He believed that autism and autistic traits are common and always have been, seeing aspects of this

> continuum in familiar archetypes from pop culture like the socially awkward scientist and the absent-minded professor. He went so far as to say, it seems that for success in science and art, a dash of autism is essential. [Bold added for emphasis.]

Wendy Chung's *TED Talks,* Autism—What We Know (and What We Don't Know Yet), presents an excellent introduction to autism (Chung, April, 2014). Quoting from her talk:

> But autism is not a single condition. It's actually a spectrum of disorders, a spectrum that ranges, for instance, from Justin, a 13-year-old boy who's not verbal, who can't speak, who communicates by using an iPad to touch pictures to communicate his thoughts and his concerns, a little boy who, when he gets upset, will start rocking, and eventually, when he's disturbed enough, will bang his head to the point that he can actually cut it open and require stitches. That same diagnosis of autism, though, also applies to Gabriel, another 13-year-old boy who has quite a different set of challenges. He's actually quite remarkably gifted in mathematics. He can multiply three numbers by three numbers in his head with ease, yet when it comes to trying to have a conversation, he has great difficulty. He doesn't make eye contact. He has difficulty starting a conversation, feels awkward, and when he gets nervous, he actually shuts down. Yet both of these boys have the same diagnosis of autism spectrum disorder.

The number of diagnosed cases of autism has risen rapidly over the past few decades. What is causing this increase? Continuing to quote Wendy Chung:

> The next question everyone wonders is, what caused autism? And a common misconception is that vaccines cause autism. But let me be very clear: **Vaccines do not cause autism.** (Applause) In fact, the original research study that suggested that was the case was completely fraudulent. It was actually retracted from the journal Lancet, in which it was published, and that author, a physician, had his medical license taken away from him. The Institute of Medicine, The Centers for Disease Control, have repeatedly investigated this and there is no credible evidence that vaccines cause autism. Furthermore, one of the ingredients in vaccines, something called thimerosal, was thought to be what the cause of autism was. That was actually removed from vaccines in the year 1992, and you can see [from the graph in the video] that it really did not have an effect in what happened with the prevalence of autism. So again, there is no evidence that this is the answer. So the question remains, what does cause autism? [Bold added for emphasis.]

Jef Akst's article, Half Genes, Half Environment, discusses the nature/nurture aspects of Autism Spectrum Disorder (Akst, 5/5/2014). Quoting from his article:

> Autism spectrum disorder (ASD), a complex developmental disease that affects nearly 1 percent of US children, **has long been recognized to have both genetic and environmental influences.** Now, through a review of more than 2 million births in Sweden between 1982 and 2006, researchers led by Sven Sandin of King's College London and the Karolinska Instijmtutet in Stockholm determined that **both the heritability of ASD the environmental component each comprise approximately 50 percent of the risk.** Moreover, children born into a family in which a sibling or cousin has previously been diagnosed with ASD are at a greatly increased risk: those with an autism-afflicted sibling have a 10-fold greater risk of being affected themselves, while those with an autism-afflicted cousin are twice as likely to be diagnosed with ASD. The

> team's results were published this weekend (May 3, 2014) in JAMA. [Bold added for emphasis.]

Temple Grandin has autism. She is well known for major contributions she has made that are dependent on her particular insights into the world. She discusses some of her work in a *TED Talks,* Temple Grandin: The World Needs All Kinds of Minds (Grandin, February, 2010.) Quoting from her presentation:

> I want to talk to you now about different ways of thinking. You have to get away from verbal language. I think in pictures, I don't think in language. Now, the thing about the autistic mind is it attends to details.
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> …
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> In my work with cattle, I noticed a lot of little things that most people don't notice would make the cattle balk. Like, for example, this flag waving, right in front of the veterinary facility. This feed yard was going to tear down their whole veterinary facility; all they needed to do was move the flag. Rapid movement, contrast. In the early '70s when I started, I got right down in the chutes to see what cattle were seeing. People thought that was crazy. A coat on a fence would make them balk, shadows would make them balk, a hose on the floor ... people weren't noticing these things …

Dyslexia

The Diagnostic and Statistical Manual Fourth Edition (DSM-IV) criteria for the diagnosis of dyslexia are:

- Reading achievement substantially below that expected for the person's age, measured intelligence and age-appropriate education.
- The disturbance in reading ability interferes with academic achievement or activities of daily living that require reading skills.
- If a sensory deficit is present, the reading difficulties are in excess of those usually associated with the specific sensory deficit.

The incidence level of dyslexia varies with the definition being used. Quoting from Dyslexia Help (n.d.):

> Dyslexia is thought to be one of the most common language-based learning disabilities. It is the most common cause of reading, writing, and spelling difficulties. Of people with reading difficulties, 70-80% are likely to have some form of dyslexia. **It is estimated that between 5-10% of the population has dyslexia, but this number can also be as high as 17%.** The symptoms of dyslexia range from mild to severe. Because dyslexia may not be recognized and diagnosed in some individuals, they do not receive the necessary treatment; others may not disclose that they are diagnosed. These mitigating factors make the prevalence of dyslexia difficult to precisely determine. [Bold added for emphasis.]

My 7/15/2015 Google search of the term *treatment for dyslexia* produced over 780 thousand results. A variety of treatment options have proven successful. They can involve intensive one-on-one instruction, small group instruction, and use of certain computer games and computer-based instruction. **Early diagnosis and treatment produces the best results**.

Many dyslexics find it quite helpful to use a word processor with a spelling checker. This becomes a valuable, everyday writing tool for them. Nowadays, many dyslexic students are allowed to use to use a word processor when taking required state and national tests.

I want to share a personal story. In the early 1970s, I created a doctoral computers-in-education program at the University of Oregon. Doctoral students typically take extensive written comprehensive tests. I allowed all my students to use a word processor when taking their comprehensive exams. The "-hit" hit the fan when some faculty members learned that my students were using their word processor's spelling check during the exam. Evidently they felt this was a type of cheating that gave my students an advantage. Fortunately, I won this battle.

But, the word processor is a small part of the more modern problem. Outside of testing situations, people routinely make use of good connectivity to the web and other computer tools as they solve problems and accomplish tasks. Such an "accommodation" is now commonplace for all students—except when taking tests. I wonder how long it will be before such an accommodation will be made available to all students when taking tests?

Dyscalculia

Quoting from the Wikipedia:

> Dyscalculia is difficulty in learning or comprehending arithmetic, such as difficulty in understanding numbers, learning how to manipulate numbers, and learning math facts. It is generally seen as a specific developmental disorder like dyslexia.
>
> Dyscalculia can occur in people from across the whole IQ range, often, but not always, involving difficulties with time, measurement, and spatial reasoning, Estimates of the prevalence of dyscalculia range between 3 and 6% of the population. A quarter of children with dyscalculia have ADHD.

Quoting from the British Dyslexia Association:

> Developmental Dyscalculia often occurs in association with other developmental disorders such as dyslexia or ADHD/ADD. Co-occurrence of learning disorders appears to be the rule rather than the exception. Co-occurrence is generally assumed to be a consequence of risk factors that are shared between disorders, for example, working memory. However, it should not be assumed that all dyslexics have problems with mathematics, although the percentage may be very high, or that all dyscalculics have problems with reading and writing. This latter rate of co-occurrence may well be a much lower percentage.

Amada Morin's website, Understanding Dyslexia, provides a broad range of information useful to parents and teachers (Morin, 3/10/2014). Quoting from the website:

> Dyscalculia can affect many different areas of math learning and performance. Different kids have different challenges.
>
> The most common problem is with "number sense." This is an intuitive understanding of how numbers work, and how to compare and estimate quantities on a number line. Most researchers agree that number sense is at the core of math learning. If kids don't understand the basics about how numbers work, learning math and using it every day can be very frustrating.
>
> …

> An estimated 6 to 7 percent of elementary school children may have dyscalculia. It's not uncommon for kids to have more than one learning issue. In fact, 56 percent of kids with a reading disorder also have poor math achievement. And 43 percent of kids with a math disability have poor reading skills.

My 7/16/2015 Google search of the expression *symptoms of dyscalculia* produced over 81 thousand results. Quoting from the section Symptoms Established by Research of the website About Dyscalculia:

> The following are seen in primary school, and well established by educational researchers:
>
> 1. Delay in counting. Five to seven year-old dyscalculic children show less understanding of basic counting principles than their peers (e.g. that it doesn't matter which order objects are counted in).
> 2. Delay in using counting strategies for addition. Dyscalculic children tend to keep using inefficient strategies for calculating addition facts much longer than their peers.
> 3. Difficulties in memorizing arithmetic facts. Dyscalculic children have great difficulty in memorizing simple addition, subtraction and multiplication facts (eg. 5 + 4 = 9), and this difficulty persists up to at least the age of thirteen.
>
> These symptoms may be caused by two more fundamental difficulties, although more research is needed to be sure:
>
> 1. Lack of "number sense." Dyscalculic children may have a fundamental difficulty in understanding quantity. They are slower at even very simple quantity tasks such as comparing two numbers (which is bigger, 7 or 9?), and saying how many there are for groups of 1-3 objects. The brain areas which appear to be affected in dyscalculia are areas which are specialized to represent quantity.
> 2. Less automatic processing of written numbers. In most of us, reading the symbol "7" immediately causes our sense of quantity to be accessed. In dyscalculic individuals this access appears to be slower and more effortful. Thus dyscalculic children may have difficulty in linking written or spoken numbers to the idea of quantity.
>
> The following are NOT likely to be symptoms of dyscalculia:
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> 1. Reversals of numbers—this is a normal developmental stage which all children go through and is no cause for alarm in itself.
> 2. Difficulty remembering names—[there is] no evidence to suggest that long term verbal memory has anything to do with dyscalculia.

Dysgraphia

Dysgraphia is a writing disability. Quoting from the Wikipedia:

> Dysgraphia is a transcription disability, meaning that it is a writing disorder associated with impaired handwriting, orthographic coding (orthography, the storing process of written words and processing the letters in those words), and finger sequencing (the movement of muscles required to write). It often overlaps with other learning disabilities

> such as speech impairment, attention deficit disorder, or developmental coordination disorder.

Rachel Pechman captures the nature of this brain disorder in her article, D is For… in which she writes about dyslexia, dysgraphia, and dyscalculia. (Pechman, October, 2010). Quoting from the article:

> When Josh was in 6th grade, his mother's concern about his handwriting reached a head. Josh's capital S still looked like the hasty squiggle of his early elementary years. His lower case n was not much more than a tiny arc. "Josh read on level, his vocabulary was fine, and his math skills were advanced," says 45-year-old Jean Steffen of Yorktown Heights, NY. "Why couldn't I read his writing?" After talking with Josh's teacher, Steffen had her son tested by a specialist. The result: Josh was diagnosed with dysgraphia, a learning disorder that affects the ability to translate thinking into motor skills in the hands. "That explained a lot, including why he is so slow at tying his sneakers," says Josh's mom. **Josh's handwriting is improving thanks to school-based occupational therapy — though he now types most of his work on a computer.** [Bold added for emphasis.]

The bolded section above emphasizes a key idea in the education of children with handicapping conditions. If a tool (such as a computer) can help the student, it is provided and the student is allowed to use it (even on tests!!!). For many people, keyboarding is both faster and more legible than handwriting. Moreover, it brings the benefits of a spelling and grammar checker, and ease in storing and editing one's work.

Continuing to quote from Pechman:

> Children with dysgraphia typically have motor and processing weaknesses that make it hard for them to get their thoughts down on paper — even when they understand the subject matter. Basically, getting words from head to hand is a challenge, says Marjorie Fessler, Ed.D., supervisor of outpatient educational services at Kennedy Krieger Institute in Baltimore. Kids with dysgraphia often also have dyslexia (and/or other neurobehavioral issues such as ADHD), so experts don't have a clear idea of how many people have dysgraphia, says Caroline DiBattisto, M.D., a developmental-behavioral pediatrician at the Medical College of Georgia. **But it is thought that 5 to 20 percent of people have some problem with handwriting.** [Bold added for emphasis.]

There are clear benefits to a student who is facile in using a computer keyboard to write, edit, retrieve information, and communicate with both people and machines. And, voice input is now widely used. Such technology has led to many schools placing less emphasis on teaching cursive handwriting. My 7/16/2015 Google search of the expression *decrease in teaching of cursive handwriting* produced over 70 thousand results. Some of the articles present information about the decline that is occurring and others provide arguments that support the teaching of cursive writing.

Brain-toxic Poisons: Lead, Mercury, and Phthalates

The general public is aware that lead damages the human brain. There are a number of other quite prevalent brain-poisoning substances that children and adults are being exposed to.

James Hamblin's article, The Toxins That Threaten Our Brains, provides an excellent introduction to brain-toxic substances (Hamblin, 3/18/2014). Quoting from the article:

> Last month, more research brought concerns about chemical exposure and brain health to a heightened pitch. Philippe Grandjean, Bellinger's Harvard colleague, and Philip Landrigan, dean for global health at Mount Sinai School of Medicine in Manhattan, announced to some controversy in the pages of a prestigious medical journal that **a "silent pandemic" of toxins has been damaging the brains of unborn children.** The experts named 12 chemicals—substances found in both the environment and everyday items like furniture and clothing—that they believed to be causing not just lower IQs but ADHD and autism spectrum disorder. Pesticides were among the toxins they identified. [Bold added for emphasis.]

The Nenurtoxins listed in the study are: manganese, fluoride, chloypyrifos, DDT/DDE, tetracloro-ethylene, polybrominated diphenyl ethers, arsenic, lead, mercury, toluene, ethanol, and polycholorinated biphenyls (PCBs). Continuing to quote from the article:

> Chlorpyrifos is just one of 12 toxic chemicals Landrigan and Grandjean say are having grim effects on fetal brain development. … The number of chemicals that they deemed to be developmental neurotoxins had doubled over the past seven years. Six had become 12. Their sense of urgency now approached panic. "Our very great concern," Grandjean and Landrigan wrote, **"is that children worldwide are being exposed to unrecognized toxic chemicals that are silently eroding intelligence, disrupting behaviors, truncating future achievements and damaging societies."** [Bold added for emphasis.]

One recommendation is that pregnant women should eat organic foods. Quoting again from Hamblin's article:

> "So you recommend that pregnant women eat organic produce?" I asked Grandjean, a Danish-born researcher who travels around the world studying delayed effects of chemical exposure on children.
>
> "That's what I advise people who ask me, yes. It's the best way of preventing exposure to pesticides." Grandjean estimates that there are about 45 organophosphate pesticides on the market, and "most have the potential to damage a developing nervous system."
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> Landrigan had issued that same warning, unprompted, when I spoke to him the week before. "I advise pregnant women to try to eat organic because it reduces their exposure by 80 or 90 percent," he told me. "These are the chemicals I really worry about in terms of American kids, the organophosphate pesticides like chlorpyrifos."

The following three sub-sections contain details of three prominent IQ-lowering toxins: lead, mercury, and phthalates.

Lead

Lead poisoning has long been known to do serious brain damage. Quoting from Alexandra Sifferlin's article, The Legacy of Lead: How the Metal Affects Academic Achievement (Sifferlin, 2/27/2013):

> While the primary sources of lead have been eliminated, the researchers report that cities still retain a "legacy" of the contamination in discarded water pipes or paint, and contaminated particles that are swept up from soil and into the air are causing an rise in blood lead levels in kids by anywhere from 11% to 14% during July through September as compared to January.

> Continued exposure to lead can have detrimental effects on children's development, according to a separate study published in the *American Journal of Public Health*. Researchers reported that early childhood lead exposure was linked to low performance in math, science and reading in elementary and junior high students—even at exposure levels lower than the federal limit. "Despite a dramatic decline in blood lead concentrations, childhood lead poisoning continues to be the most important and preventable environmental problem among children and contributes significantly to the burden of childhood diseases," the authors write.
>
> In the study, the scientists studied blood lead levels in 21,281 kids who had been tested before age six between 1990 and 2008. They then compared these levels to their math, science and reading scores on the Michigan Education Assessment Program tests from 2008-2010. They found that high blood levels before age six was associated with low academic performance in grades 3, 5 and 8 [which were the grade levelstested].

Jack Lewis provides a history of lead poisoning in his article, Lead Poisoning: A Historical Perspective (Lewis, May, 1985). Quoting from the article:

> The Romans were aware that lead could cause serious health problems, even madness and death. However, they were so fond of its diverse uses that they minimized the hazards it posed. Romans of yesteryear, like Americans of today, equated limited exposure to lead with limited risk. What they did not realize was that their everyday low-level exposure to the metal rendered them vulnerable to chronic lead poisoning, even while it spared them the full horrors of acute lead poisoning.
>
> The symptoms of acute lead intoxication appeared most vividly among miners who were thrown into unhealthy intimacy with the metal on a daily basis. Romans reserved such debilitating and backbreaking labor for slaves. Some of these unfortunates were forced to spend all of their brief and blighted lives underground, out of sight and out of mind. The unpleasantness of lead mining was further neutralized late in the Empire when the practice was prohibited in Italy and consigned completely to the provinces.

Now jump forward two thousand years. In 1921, it was determined that the addition of tetraethyl lead to gasoline greatly improved performance in high compression engines. It took until 1975 before pollution-reduction catalytic converts were developed, and eventually unleaded gasoline came into general usage.

Lead paint has a similarly long history, dating back at least to the 4th century BCE. Quoting from the Wikipedia:

> Lead is added to paint to speed up drying, increase durability, maintain a fresh appearance, and resist moisture that causes corrosion. It is one of the main health and environmental hazards associated with paint. In some countries, lead continues to be added to paint intended for domestic use,[1] whereas countries such as the U.S. and the U.K. have regulations prohibiting this, although lead paint may still be found in older properties painted prior to the introduction of such regulations. Although lead has been banned from household paints in the United States since 1978, paint used in road markings may still contain it.

Mercury

Quoting from the Wikipedia:

> Common symptoms of mercury poisoning include peripheral neuropathy (presenting as paresthesia or itching, burning or pain), skin discoloration (pink cheeks, fingertips and toes), swelling, and desquamation (shedding or peeling of skin).
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> …
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> Affected children may show red cheeks, nose and lips, loss of hair, teeth, and nails, transient rashes, hypotonia (muscle weakness), and increased sensitivity to light. Other symptoms may include kidney dysfunction (e.g. Fanconi syndrome) or neuropsychiatric symptoms such as emotional lability, memory impairment, and / or insomnia.
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> …
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> Consumption of whale and dolphin meat, as is the practice in Japan, is a source of high levels of mercury poisoning. Tetsuya Endo, a professor at the Health Sciences University of Hokkaido, has tested whale meat purchased in the whaling town of Taiji and found mercury levels more than 20 times the acceptable Japanese standard.
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> …
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> Human-generated sources, such as coal-burning power plants emit about half of atmospheric mercury, with natural sources such as volcanoes responsible for the remainder.

Exposure to mercury while in a mother's womb is a significant danger. Quoting from John Esterbrook's article, Study: IQ Loss from Mercury Costly (Esterbrook, 3/1/2005):

> The Mount Sinai Center for Children's Health and the Environment combined a number of previous studies to determine hundreds of thousands of babies are born every year with lower IQ associated with mercury exposure.
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> …
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> As an example, Trasande said about 4 percent of babies [in the United States] , or about 180,000, are born each year with blood mercury levels between 7.13 and 15 micrograms per liter. That level of mercury, the group concluded, causes a loss of 1.6 IQ points.
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> Mercury levels, Trasande said, are probably lower generally than they were in years before limits were placed on emissions from medical waste and municipal incinerators.
>
> "We've made great progress in reducing mercury emissions over the past decade, and this is likely to have reduced the number of affected children and to have reduced costs by a similar amount," Trasande said.

Phthalates

Quoting from National Biomonitoring Program:

> Phthalates are a group of chemicals used to make plastics more flexible and harder to break. They are often called plasticizers. Some phthalates are used as solvents (dissolving agents) for other materials. They are used in hundreds of products, such as vinyl flooring, adhesives, detergents, lubricating oils, automotive plastics, plastic clothes (raincoats), and personal-care products (soaps, shampoos, hair sprays, and nail polishes).

> Phthalates are used widely in polyvinyl chloride plastics, which are used to make products such as plastic packaging film and sheets, garden hoses, inflatable toys, blood-storage containers, medical tubing, and some children's toys.

Quoting from Timothy Paul's article, Exposure During Pregnancy to Common Household Chemicals Associated with Substantial Drop in Child IQ (Paul, 12/10/2014):

> Children exposed during pregnancy to elevated levels [that is, levels found in the upper 25% of children in the study] of two common chemicals found in the home—di-n-butyl phthalate (DnBP) and di-isobutyl phthalate (DiBP)—**had an IQ score, on average, more than six points lower than children exposed at lower levels,** according to researchers at Columbia University's Mailman School of Public Health.
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> …
>
> DnBP and DiBP are found in a wide variety of consumer products, from dryer sheets to vinyl fabrics to personal care products like lipstick, hairspray, and nail polish, even some soaps. Since 2009, several phthalates have been banned from children's toys and other childcare articles in the United States. However, no steps have been taken to protect the developing fetus by alerting pregnant women to potential exposures. In the U.S., phthalates are rarely listed as ingredients on products in which they are used.
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> …
>
> Children of mothers exposed during pregnancy to the highest 25 percent of concentrations of DnBP and DiBP had IQs 6.6 and 7.6 points lower, respectively, than children of mothers exposed to the lowest 25 percent of concentrations after controlling for factors like maternal IQ, maternal education, and quality of the home environment that are known to influence child IQ scores. The association was also seen for specific aspects of IQ, such as perceptual reasoning, working memory, and processing speed. [Bold added for emphasis.]

This section discussed three of a multitude of poisons that affect human cognition. We know enough about some of these that we can greatly reduce the damage being done. Lead provides a good example. Typically, a combination of national (indeed, international) action at governmental levels, and education of the people being most affected, seems to be a good approach to decreasing such problems. As with many problems, the economics of the situations is an important issue. In coal-fired generation of electricity, for example, we know that there are mercury emissions. These can be reduced, but it is expensive to do so.

Final Remarks

The brain is an amazingly complex organ. Brain disorders can come from nature, nurture, or some combination of the two.

Think about the initial development of your brain and the rest of your body. A sperm and an egg combine to form one cell. This one cell eventually becomes many billions of cells. Within your brain, there are trillions of connections.

The results of this growth process are such that no two people (not even identical twins) are the same. In some cases, differences produced by nature, added to the differences caused by nurture, and/or a combination of nature and nurture, are modest. In other cases they can be huge.

A significant percentage of students have individual differences that are particularly challenging to them as they try to participate in our educational system. In 1975, the U.S. Federal Government passed the *Education for All Handicapped Children Act*. Through this law and its modifications over the years, certain disabilities are defined, rights of children with these disabilities are defined, and funds are provided for schools to help meet the special requirements of these children.

Our steadily increasing knowledge about the human brain, and our steadily improving methods of diagnostic testing, have contributed greatly to improving the lives of students. Our understanding of how the brain/mind works is making amazing progress. However, the brain/mind is very complex, and the problems being studied are very challenging. The future of this discipline of study today is quite bright, and we will see continuing progress for many years to come.

You and Your Students

As a teacher and/or parent, you are a first line of defense for our children. While we would all like to trust that our lawmakers and public agencies are "doing right" by our children, there are a great many situations in which they are not.

You have heard the statement by Thomas Jefferson and others, "Eternal vigilance is the price of liberty." In raising and educating children, eternal vigilance is a routine and ongoing part of the job. This means that a major goal of education needs to be to help students learn to provide part of that vigilance for themselves, and for all parents and teachers to become part of the network/web providing that vigilance.

One of the benefits of free and fully integrated public schools is that students are routinely exposed to a cross section of humanity. This type of school environment provides excellent opportunities to learn from and about one's peers.

As a teacher and/or parent, think back over the content of this chapter. Select a topic that seems particularly relevant to you and the students you work with. Is your knowledge of the topic adequate to the challenges you face? What do you want the students you interact with to know? For the topic you select, interact with students to gain insights into their insights, and to guide them in gaining increased knowledge appropriate to their needs.

After you make progress in this personal and experiential growth, select a second topic from the chapter. Set yourself a goal for professional and parental growth.

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> "Why?" "Why?" is a question that parents ask me all the time. "Why did my child develop autism?" As a pediatrician, as a geneticist, as a researcher, we try and address that question.

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> Lower IQ levels linked to mercury exposure in the womb costs the United States $8.7 billion a year in lost earnings potential, according to a study released Monday by researchers at a New York hospital.

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> Temple Grandin, diagnosed with autism as a child, talks about how her mind works—sharing her ability to "think in pictures," which helps her solve problems that neurotypical brains might miss. She makes the case that the world needs people on the autism spectrum: visual thinkers, pattern thinkers, verbal thinkers, and all kinds of smart geeky kids.

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> Leading scientists recently identified a dozen chemicals as being responsible for widespread behavioral and cognitive problems. But the scope of the chemical dangers in our environment is likely even greater.

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Brain imaging pioneer Nancy Kanwisher, who uses fMRI scans to see activity in brain regions (often her own), shares what she and her colleagues have learned: The brain is made up of both highly specialized components and general-purpose "machinery." Another surprise: There's so much left to learn.

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The decades-old controversy over the use of lead as a fuel additive is a mere footnote to centuries of controversy over this remarkably useful but also insidiously deadly metal.

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Dyscalculia is a learning issue that causes serious math difficulties. It isn't as well known as dyslexia. However, some researchers now think it may be almost as common.

Paul, T.S. (12/10/2014). Exposure during pregnancy to common household chemicals associated with substantial drop in child IQ. Columbia University Mailman School of Public Health. Retrieved 7/19/2015 from http://www.mailman.columbia.edu/print/5988. Quoting from the article:

"Pregnant women across the United States are exposed to phthalates almost daily, many at levels similar to those that we found were associated with substantial reductions in the IQ of children," says lead author [of the 326 children study] Pam Factor-Litvak, PhD.

Pechman, R. (October, 2010). D is for…. *Scholastic.* Retrieved 7/16/2015 from http://www.scholastic.com/browse/article.jsp?id=3754779.

Dyslexia, dysgraphia, and dyscalculia are three common learning disorders that are sometimes the cause of early struggles with reading, writing, and arithmetic.

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Developmental disorders in children are typically diagnosed by observing behavior, but Aditi Shankardass suggests we should be looking directly at brains. She explains how one EEG technique has revealed mistaken diagnoses and transformed children's lives.

Sifferlin, A. (2/27/2013). The legacy of lead: How the metal affects academic achievement. *Time.* Retrieved 7/22/2015 from http://healthland.time.com/2013/02/27/the-legacy-of-lead-how-the-metal-affects-academic-achievement/. Quoting from the article:

Lead poisoning is still a concern for American families, especially those living in urban areas where older housing materials remain sources of potential exposure.

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> Decades ago, few pediatricians had heard of autism. In 1975, 1 in 5,000 kids was estimated to have it. Today, 1 in 68 is on the autism spectrum. What caused this steep rise?

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A major component of this presentation is a summary of causes of ADHD-like behavior that leads to a misdiagnosis of ADHD. Sousa argues that many children receive behavior modification medication when their symptoms can be treated without the use of drugs.

Strauss, V. (7/8/2014). Why so many children can's sit still in school today. *The Washington Post.* Retrieved 1/28/2015 from http://www.washingtonpost.com/blogs/answer-sheet/wp/2014/07/08/why-so-many-kids-cant-sit-still-in-school-today/. This article is mainly a copy of a blog entry posted by Angela Hanscom. Quoting Hanscom:

> The problem: children are constantly in an upright position these days. It is rare to find children rolling down hills, climbing trees, and spinning in circles just for fun. Merry-go-rounds and teeter-totters are a thing of the past.

Chapter 9. Brain Damage

According to the Brain Injury Association:

- 5.3 million Americans currently live with a disability resulting from a traumatic brain injury (TBI)
- 1.5 million people sustain a TBI each year
- each year 50,000 Americans die due to TBI

Many people suffer traumatic brain injuries in accidents. The statistics given above suggest that many people suffering such injuries eventually recover, but that many others suffer continuing disabilities.

People also suffer brain injuries in strokes and via brain diseases such as Alzheimer's. This chapter provides a brief introduction to some types of brain injuries. It also includes a discussion of cognitive reserve—having a brain in "good shape" so that it can more effectively cope with and/or recover from some level of injury.

Try to imagine how a brain can continue to function well as some of its neurons die from old age, disease, or brain damage. Compare this "fail softly" fault tolerance of a human brain's performance with that of early electronic digital computers that failed completely from the failure of one small part. (Some fault tolerance is now built into modern computers.)

Concussions and Cognitive Reserve

Your brain has a consistency of soft butter. A blow to the head "sloshes" your brain and damages brain cells. The following definition is from the Mayo Clinic:

> A concussion is a traumatic brain injury that alters the way your brain functions. Effects are usually temporary but can include headaches and problems with concentration, memory, balance and coordination.
>
> …
>
> Concussions are common, particularly if you play a contact sport, such as football. But every concussion injures your brain to some extent. This injury needs time and rest to heal properly. Most concussive traumatic brain injuries are mild, and people usually recover fully.

Many different sports carry the threat of concussion. Robert Pearl's article, A Doctor's Take On Sports-Related Concussions, provides a good introduction to sports-related concussions (Pearl, 4/17/2014). Quoting from the article:

> Still, the Center for Disease Control (CDC) estimates that as many as 3.8 million sports-related traumatic brain injuries occur in the United States each year, most of which go unreported and untreated.
> The CDC has clarified the impact that this complex pathological and physiological process has on the brain and provided treatment recommendations. Neurologists and sports medicine physicians have started to recognize that when the brain is not given

> enough time to heal from injury, concussions produce a wide range of **chronic problems that affect the way individuals think, learn, and act.**
>
> …
>
> A study from McGill University in Montreal found 60 percent of college soccer players reported concussion symptoms at least once during a season. The University of Pittsburgh's Brain Trauma Research Center estimates 34 percent of college football players have had one concussion while 20 percent have endured multiple concussions. [Bold added for emphasis.]

Currently there are many research projects on how to prevent concussions, how to reduce the severity of concussions, and how to treat concussions. A number of articles on concussion talk about *cognitive reserve*. Quoting from the Wikipedia:

> The term cognitive reserve describes the mind's resistance to damage of the brain. … There are two models that can be used when exploring the concept of "reserve": brain reserve and cognitive reserve. These terms, albeit often used interchangeably in the literature, provide a useful way of discussing the models. **Using a computer analogy brain reserve can be seen as hardware and cognitive reserve as software.** All these factors are currently believed to contribute to global reserve. Cognitive reserve is commonly used to refer to both brain and cognitive reserves in the literature. [Bold added for emphasis.]

A person's level of education is a factor in recovery from a concussion. Quoting from Jon Hamilton's article, Education May Help Insulate The Brain Against Traumatic Injury (Hamilton, 4/23/2014):

> A little education goes a long way toward ensuring you'll recover from a serious traumatic brain injury. **In fact, people with lots of education are seven times more likely than high school dropouts to have no measurable disability a year later.**
>
> "It's a very dramatic difference," says Eric Schneider, an epidemiologist at Johns Hopkins and the lead author of a new study. The finding suggests that people with more education have brains that are better able to "find ways around the damage" caused by an injury, he says.
>
> …
>
> One reason for the difference may be something known as "cognitive reserve" in the brain, Schneider says. The concept is a bit like physical fitness, he says, which can help a person recover from a physical injury. Similarly, a person with a lot of cognitive reserve may be better equipped to recover from a brain injury. [Bold added for emphasis.]

The basic concept of cognitive reserve applies to all types of brain damage. For example, Adrienne Tucker and Yaakov Stern have written about Cognitive Reserve in Aging (Tucker & Stern, 6/1/2011). Quoting from their research paper:

> Cognitive reserve explains why those with higher IQ, education, occupational attainment, or participation in leisure activities evidence less severe clinical or cognitive changes in the presence of age-related or Alzheimer's disease pathology. Specifically, the cognitive reserve hypothesis is that individual differences in how tasks are processed provide reserve against brain pathology. Cognitive reserve may allow for more flexible strategy

> usage, an ability thought to be captured by executive functions tasks. Additionally, cognitive reserve allows individuals greater neural efficiency, greater neural capacity, and the ability for compensation via the recruitment of additional brain regions. Taking cognitive reserve into account may allow for earlier detection and better characterization of age-related cognitive changes and Alzheimer's disease. Importantly, cognitive reserve is not fixed but continues to evolve across the lifespan. Thus, even late-stage interventions hold promise to boost cognitive reserve and thus reduce the prevalence of Alzheimer's disease and other age-related problems.
>
> …
>
> According to the brain reserve model, there is some threshold at which clinical deficits will become apparent and those individuals with more brain reserve require more pathology to reach that threshold. That is, in the case of Alzheimer's for example, the disease will progress longer and more pathology will accumulate before deficits will be seen in those that start out with a bigger brain and/or more neurons.

In summary, there is substantial research evidence that a person is well served by a good and continuing informal and formal education that builds cognitive reserve. The often-quoted statement, "use it or lose it" applies both to one's physical body and to one's brain/mind! And—for those of us scholarly types such as your author who are "somewhat" beyond middle age, there is comfort in knowing that our years of continuing cognitive efforts are serving us well.

Poverty Contributes to Lower Cognitive Performance

There have been many research studies on the negative cognitive and other effects that poverty has on children. Each country sets its own definition of what constitutes poverty. In the United States, the definition is such that a large percentage of PreK-12 students are living in poverty. Quoting from Lyndsey Layton's article, Majority of U.S. Public School Students Are in Poverty (Layton, 1/16/2015):

> The Southern Education Foundation reports that 51 percent of students in pre-kindergarten through 12th grade in the 2012-2013 school year were eligible for the federal program that provides free and reduced-price lunches. The lunch program is a rough proxy for poverty, but the explosion in the number of needy children in the nation's public classrooms is a recent phenomenon that has been gaining attention among educators, public officials and researchers.
>
> The shift to a majority-poor student population means that in public schools, a growing number of children start kindergarten already trailing their more privileged peers and rarely, if ever, catch up. They are less likely to have support at home, are less frequently exposed to enriching activities outside of school, and are more likely to drop out and never attend college.

The effects of poverty on students are not a new finding. Quoting from Robert Sander's 2008 article, EEGs Show Brain Differences between Poor and Rich Kids (Sanders, 12/2/2008):

> In a study recently accepted for publication by the *Journal of Cognitive Neuroscience,* scientists at UC Berkeley's Helen Wills Neuroscience Institute and the School of Public Health report that normal 9- and 10-year-olds differing only in socioeconomic status have detectable differences in the response of their prefrontal cortex, the part of the brain that is critical for problem solving and creativity.

> …
>
> "Kids from lower socioeconomic levels show brain physiology patterns similar to someone who actually had damage in the frontal lobe as an adult," said Robert Knight, director of the institute and a UC Berkeley professor of psychology. "We found that kids are more likely to have a low response if they have low socioeconomic status, though not everyone who is poor has low frontal lobe response."
>
> …
>
> "This is a wake-up call," Knight said. "It's not just that these kids are poor and more likely to have health problems, but they might actually not be getting full brain development from the stressful and relatively impoverished environment associated with low socioeconomic status: fewer books, less reading, fewer games, fewer visits to museums."
>
> Kishiyama, Knight, and Boyce suspect that the brain differences can be eliminated by proper training. They are collaborating with UC Berkeley neuroscientists who use games to improve the prefrontal cortex function, and thus the reasoning ability, of school-age children.

Carolyn Gregoire's article, Study Reveals Sad Link Between Poverty And Children's Brain Development, presents research on the effects of poverty (Gregoire, 3/31/2015). Quoting from the article:

> Researchers from nine universities across the country, led by neuroscientists at Children's Hospital Los Angeles and Columbia University Medical Center, conducted a major new study of the effects of family income and parental education on child and adolescent brain development.
>
> The researchers studied nearly 1,100 individuals between the ages of 3 and 20, collecting data on their socioeconomic situation and conducting MRI brain scans and cognitive tests measuring executive functions like self-control and anticipation of consequences.
>
> The results revealed a strong positive association between family income and brain surface area, largely in those brain areas that are linked to skills instrumental in learning and academic success.
>
> The brain of "the kid whose family makes less than $25,000 is about 6 percent smaller in surface area than the kid whose family made $150,000," Sowell said.
>
> Higher family income was also associated with better performance on tests of executive function. The researchers hypothesize that the better performance is linked to the greater brain surface area.

Stress

A great deal is known about how stress affects both brain functioning and general health. Information Age Education published a sequence of four IAE newsletters on the topic of Stress and Education (Moursund & Sylwester, April, 2011). Quoting from the newsletter:

> We have an innate rapid response system for such imminent dangers and opportunities. You are probably familiar with the terms "fight, freeze, or flight" as response possibilities when your brain senses a possible life-threatening problem situation. In 1975 pioneer

> researcher Hans Selye called this the **stress response.** (See http://en.wikipedia.org/wiki/Hans_Selye.) The stress response evolved to set priorities on the expenditure of body/brain energy when confronting an extraordinary imminent challenge. The stress response:
>
> - Temporarily increases energy flow to the body/brain systems that enhance an assertive response to the current challenge, such as our circulation, respiration, attention, and motor systems, and
> - Temporarily decreases energy flow to the systems that aren't necessary for a rapid assertive response to the current challenge, such as our digestion, immune, and sexual arousal systems.
>
> …
>
> Chronic stress is physically and mentally debilitating because it uses a short-term high-energy response system geared to physical danger and opportunity to deal with a problem that's typically doesn't portend physical injury. For example, a teacher getting stressed out for days on end because of classroom misbehavior is counterproductive. Better to engage your problem solving capabilities in creating a classroom environment that reduces misbehavior.
>
> …
>
> No negative long-term effects result from periodic short term shut downs of our rational problem solving system, but chronic shutdowns will eventually cause serious problems with the system. For more than 25 years we have know that chronic stress impairs hippocampal function leading to:
>
> - Neuronal atrophy and destruction of neurons,
> - Decreased short term memory, and
> - Decreased contextual memory.

Sleep Disorders and Sleep Deprivation

Quoting from the Wikipedia:

> Sleep deprivation can adversely affect the brain and cognitive function. A 2000 study, by the UCSD School of Medicine and the Veterans Affairs Healthcare System in San Diego, used functional magnetic resonance imaging (fMRI) technology to monitor activity in the brains of sleep-deprived subjects performing simple verbal learning tasks. The study showed that regions of the brain's prefrontal cortex, an area that supports mental faculties such as working memory and logical and practical ("means-ends") reasoning, displayed more activity in sleepier subjects. **Researchers interpreted this result as indicating that the brain of the average sleep-deprived subject had to work harder than that of the average non-sleep-deprived subject to accomplish a given task, and from this indication they inferred the conclusion the brains of sleep-deprived subjects were attempting to compensate for adverse effects caused by sleep deprivation.** [Bold added for emphasis.]

There has been considerable research on the effects of secondary school students and adults not getting enough sleep. For a comprehensive introduction to this topic, see the National Sleep

Foundation website at http://www.sleepfoundation.org. For example, here is a quote from the National Sleep Foundation about adult sleep needs (National Sleep Foundation, n.d.):

> "Early to bed, early to rise makes a man healthy, wealthy and wise," said Ben Franklin. But does this adage apply to teenagers? Research in the 1990s found that later sleep and wake patterns among adolescents are biologically determined; the natural tendency for teenagers is to stay up late at night and wake up later in the morning. This research indicates that school bells that ring as early as 7:00 a.m. in many parts of the country stand in stark contrast with adolescents' sleep patterns and needs.
>
> Evidence suggests that teenagers are indeed seriously sleep deprived. A recent poll conducted by the National Sleep Foundation found that 60% of children under the age of 18 complained of being tired during the day, according to their parents, and 15% said they fell asleep at school during the year.

Sleep research is beginning to give us an understanding about why we need sleep. Quoting from Barbara Mantel's article, A Good Night's Sleep Scrubs Your Brain Clean, Researchers Find (Mantel, 9/17/2013):

> It's no secret that too little shut-eye can drain your brain, but scientists haven't fully understood why.
>
> Now, a new study suggests that a good night's sleep leaves you feeling sharp and refreshed because a newly discovered system that scrubs away neural waste is mostly active when you're at rest.
>
> It's a revelation that could not only transform scientists' fundamental understanding of sleep, but also point to new ways to treat disorders such as Alzheimer's disease, which are linked to the accumulation of toxins in the brain.
>
> "We have a cleaning system that almost stops when we are awake and starts when we sleep. It's almost like opening and closing a faucet—it's that dramatic," says Dr. Maiken Nedergaard, co-director of the Center for Translational Neuromedicine at the University of Rochester Medical Center.

Addictions: Drugs and Games

Brain Science research is contributing to our understanding of addiction. What is being learned applies to:

- various *hard* drugs leading to physical addiction, such as such alcohol, cocaine, heroin;
- *soft* drugs that may lead to psychological dependence such as marijuana and LSD;
- drugs producing a strong dependence such as cocaine; and
- gambling and some types of games and entertainment.

A short introduction to addictions is provided in Richard Grant's article, Just Can't Get Enough (Grant, 11/11/2010).) This article presents some of the work of David Nutt, and includes a short video by Nutt.

In David Nutt's short video, he discusses alcohol, heroin, and gambling. His research focuses on the underling brain aspects of addictions—what parts of the brain are involved and what is going on in these parts when a person is acting under the influence of addiction.

While many of the *hard* addictive agents are illegal under the laws of many countries, some, such as alcohol and nicotine, are not. Consider nicotine. Quoting from the site http://luxury.rehabs.com/drug-addiction/what-is-the-most-addictive-drug/ :

> The most addictive drugs include cocaine and heroin; however, one of the most addictive drugs is not an illegal drug consumed only by druggies or people on the streets. It is a legal drug that is sold in grocery stores, drug stores, gas stations and many other places. Many people use it every day – several times a day even – and may not consider a drug. It's called nicotine, the main ingredient in cigarettes. According to the Substance Abuse and Mental Health Services Administration (SAMHSA), 72 million people in the United States have used nicotine. Nicotine is responsible for 440,000 deaths every year in the United States and is the most preventable cause of death.
>
> According to News Medical, nicotine is highly addictive because it automatically kicks the nervous system into gear upon use. It stimulates the body and makes it feel good. However, once the high goes away, depression and fatigue can set in. Nicotine can also cause severe health problems such as emphysema, lung cancer and other potentially deadly lung-related disorders.

E-cigarettes are now widely used as a nicotine delivery system. Quoting from the Wikipedia:

> An electronic cigarette (e-cig or e-cigarette), personal vaporizer (PV) or electronic nicotine delivery system (ENDS) is a battery-powered vaporizer that simulates the feeling of smoking. The user automatically activates the e-cigarette by taking a puff, other devices turn on by pressing a button manually. They are often cylindrical, with many variations. Their use is commonly called vaping.

What makes one drug more addictive than another? It has to do with several properties of a drug. Quoting from http://www.drugwarfacts.org/cms/Addictive_Properties#sthash.bSBv0l14.dpbs, addictive drugs have the properties:

- Withdrawal: Presence and severity of characteristic withdrawal symptoms.
- Reinforcement: A measure of the substance's ability, in human and animal tests, to get users to take it again and again, and in preference to other substances.
- Tolerance: How much of the substance is needed to satisfy increasing cravings for it, and the level of stable need that is eventually reached.
- Dependence: How difficult it is for the user to quit, the relapse rate, the percentage of people who eventually become dependent, the rating users give their own need for the substance and the degree to which the substance will be used in the face of evidence that it causes harm.
- Intoxication: Though not usually counted as a measure of addiction in itself, the level of intoxication is associated with addiction and increases the personal and social damage a substance may do.

Computer games have some addictive qualities similar to those given in the above list. I (David Moursund), am somewhat addicted to computer games (Moursund, 12/14/2012.)

A great many people have somewhat similar addictions to various forms of electronic entertainment. And, the games need not be electronic. A number of years ago, a very smart graduate student—and good friend of mine—flunked out of a doctoral program mainly due to his addiction to solitaire games played with one or two decks of cards.

Marijuana

Marijuana (pot) has long been a popular drug. Legalization in a state seems to lead to greater use by kids. Quoting from Eric Schulzke's article, Dumb and Dumber? Teen Marijuana Use Linked to Lower IQ in Later Life (Schulzke, 5/20/2014):

> Earlier this month, three researchers at the National Institute of Drug Abuse published an article in the New England Journal of Medicine surveying the current state of the evidence. According to their report, marijuana use in adolescence and early adulthood may measurably lower users' IQ decades later down the road.
>
> They conclude there is reason to believe marijuana may permanently harm the adolescent brain. Until the age of 21, the piece notes, the brain "is intrinsically more vulnerable than a mature brain to the adverse long-term effects of environmental insults."
>
> …
>
> The Office of National Drug Control Policy reported last year that one in four Boulder County high school students now use pot — more than three times the national average.
>
> And the numbers are shifting fast. In Adams County, a Denver suburb, high school marijuana use jumped from 21 percent in 2008 to 29 percent in 2012. Middle school pot use in Adams County jumped 50 percent during that period — from 5.7 to 8.5 percent.

It appears that the United States is moving toward the situation where use of marijuana will be widely acceptable, somewhat like the use of alcohol.

Alcohol

Paraphrasing from the Wikipedia:

> Alcoholism, also known as alcohol use disorder (AUD) and alcohol dependence syndrome, is a broad term for any drinking of alcohol that results in problems. It was previously divided into two types: alcohol abuse and alcohol dependence.
>
> In a medical context, alcoholism is said to exist when two or more of the following are present:
>
> - a person drinks large amounts over a long time period,
> - a person has difficulty cutting down,
> - acquiring and drinking alcohol takes up a great deal of time,
> - alcohol is strongly desired,
> - usage results in not fulfilling responsibilities,
> - usage results in social problems,

- usage results in health problem, usage results in risky situations,
- withdrawal occurs when stopping, and alcohol tolerance has occurred to use. Alcohol use can affect all parts of the body but particularly affects the brain, heart, liver, pancreas, and immune system. This can result in mental illness, Wernicke Korsakoff syndrome, an irregular heart beat, liver failure, and an increase the risk of cancer, among other disease. Drinking during pregnancy can cause damage to the baby resulting in fetal alcohol spectrum disorders.

Cognition-Enhancing Drugss

My 7/23/2015 Google search of the expression *cognition enhancing drugs* produced about 165 thousand results. Such drugs are used in the treatment of people with cognitive deficits, but are also used by perfectly healthy individuals.

Quoting from the Masud Husain and Mitul Mehta's article, Cognitive Enhancement by Drugs in Health and Disease (Husain & Mehta, January, 2011):

> Although most of the reported positive effects of such drugs have been modest in magnitude overall and are highly variable across individuals, they have had an enormous impact, stimulating interest in cognitive enhancement not only for patients with brain disorders, but also for healthy individuals. Compounds such as methylphenidate and modafinil are used by students in pursuit of better grades, military personnel who need to remain awake for long missions, elderly individuals afraid of cognitive decline and even university academics keen to maintain their performance

Caffeine is an example of a widely used cognitive-enhancing drug. Latharsha Gatlin reports on this in her article, Caffeine Has Positive effect on Memory, Johns Hopkins Researchers Say (Gatlin, 1/12/2014). Quoting from the article:

> … Michael Yassa, a neuroscientist at the University of California, Irvine, recruited 160 adults who normally consume only minimal amounts of caffeine. The volunteers first studied images of objects, before randomly receiving a pill containing either 200 milligrams of caffeine – equivalent to two espressos – or a placebo. Receiving the caffeine after studying the images helped to isolate the effect of caffeine on memory, as you wouldn't expect alertness to matter at this point.
>
> He concludes that caffeine enhances long-term memory by improving the process of memory consolidation. "This doesn't mean people should only drink coffee after they've studied, and not before," says Yassa. "I think you would get the boost regardless." That's because the process of consolidation is likely to begin as soon as new memories form.

Caffeine is not the only widely used memory enhancer. Ritalin has a long history of such use. A newer drug, Modafinil, is now popular. Quoting from Steve Bird's article, The Dangers for Students Addicted to Brain Viagra: Drugs Claimed to Boost Your Intellect Are Sweeping Universities – But at What Cost? (Bird, 10/9/2013): Quoting from this article:

> … a new inquiry suggests that up to a quarter of students at some leading universities have experimented with [Modafinil].
>
> As a result, a highly profitable black market has developed in this and other prescription-only medicines designed to treat acute neurological conditions.

> [In the U.K] Modafinil pills are being sold for as little as 50p each and have been proven to improve memory by 10 per cent. They keep users alert and awake, increasing their ability to concentrate and process information.
>
> …
>
> It took just minutes of trawling the internet for the Mail to be able to buy Modafinil for just 50p a pill from a Hong Kong website. Ten stronger tablets were also purchased for just £17 from a man in Dorset who posted his email address on student internet forums and offered to sell the drug. They all arrived within a week.

The use of drugs to enhance physical performance is widespread—especially in competitive sports. Methods have been developed to test for such drug use, and a number of well-known sports figures have been "punished" for inappropriate use of drugs. The use of cognition enhancing drugs has not received the same level of scrutiny and attempts at control. This is an interesting and challenging problem in education.

The Aging Brain

In 2015, The National Academy of Sciences published a report, Cognitive Aging: Progress in Understanding and Opportunities for Action (Blazer, et al., 2015). Quoting from this report:

> Of the abilities people hope will remain intact as they get older, perhaps the most treasured is to "stay sharp"—to think clearly, remember accurately, and make decisions with careful thought. Yet the brain ages. **Cognitive functioning in older adults can improve in some areas, such as those related to wisdom and experience, and they can decline in others, such as memory, attention, and speed of processing.** Individuals vary widely in the specific cognitive changes that occur with age, in the nature and extent of cognitive aging, as well as in the ways these changes affect daily life.
>
> …
>
> Cognition refers to the mental functions involved in attention, thinking, understanding, learning, remembering, solving problems, and making decisions. It is a fundamental aspect of an individual's ability to engage in activities, accomplish goals, and successfully negotiate the world. Although cognition is sometimes equated with memory, cognition is multidimensional because it involves a number of interrelated abilities that depend on brain anatomy and physiology. Distinguishing among these component abilities is important since they play different roles in the processing of information and behavior and are differentially impacted by aging.
>
> …
>
> Age-related changes in cognition are highly variable from one individual to the next. This variability is explained in part by differences in life experience, health status, lifestyle, education, attitudinal and emotional factors, socioeconomic status, and genetics. The trajectory of cognitive change also varies for different cognitive functions—memory, decision making, learning, speed of processing, and so on. **Further, older age is not associated only with decline; some aspects of cognition, such as wisdom, remain stable in the older decades and aspects of intelligence, such as knowledge, may actually increase with age until the very later decades.** [Bold added for emphasis.]

Kerry Grens' article, Cognitive Decline More Swift in Women, indicates that there is a substantial difference between how women's and men's brains are affected by dementia (Grens, 7/22/2015). Quoting from this article:

> Men with mild cognitive impairment stave off steep declines in mental function better than their female counterparts, according to results presented this week (July 21, 2015) at the Alzheimer's Association International Conference. Women's cognitive abilities slipped twice as fast as men's over the course of an eight-year study, Katherine Amy Lin of Duke University Medical Center and her colleagues reported.
>
> "Our findings suggest that men and women at risk for Alzheimer's may be having two very different experiences," Lin said in a press release. "These results point to the possibility of as yet undiscovered gender-specific genetic or environmental risk factors that influence the speed of decline." The aging brain (and especially Alzheimer's and other dementia) is a worldwide problem. Thus, there are many research projects addressing the problem.
>
> …
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> In another study presented at the conference, Katie Schenning of Oregon Health & Science University and her colleagues found that women experience cognitive declines faster after surgery with anesthesia than men.

Japan is leading the world in developing robots that can help provide care to the elderly. Quoting from James Vincent's article, Japanese 'Robots With a Heart' Will Care For the Elderly and Children (Vincent, 6/5/2014):

> Over 22 per cent of Japan's population is currently aged 65 or older and many companies are working on robots that can assist the elderly. Although some have human-like limbs to help move and carry objects, others are designed to offer therapeutic care instead.
>
> …
>
> Japanese technology giant SoftBank has unveiled a robot they claim is capable of understanding human emotions using an "emotional engine" and cloud-based AI.
>
> Standing roughly a meter tall with a tablet computer fixed to its chest, 'Pepper' will go on sale to the public next year for 198,000 yen (£1,150), with its creators hoping it will be using in a range of roles from caring from the elderly to baby-sitting.
>
> …
>
> Pepper reportedly learns from human interactions, with each experience helping to teach a cloud-based AI shared by all units. It has fully articulated arms and hands but moves about on wheels hidden under a curved plastic skirt.

We have grown accustomed to the idea of robots working in factories, and the cost per hour of work being quite a bit less than a "decent" hourly rate of pay for a human. It is far more challenging to build a robot that can serve as a companion and provide a wide range of services to a elderly person who may have dementia. However, this is a huge and growing market, and many companies are doing research and development in this area.

Final Remarks

This chapter provides brief introductions to a wide range of brain injury topics that are important to teachers and their students, and also to parents and their children. Key ideas covered in this chapter include detection of possible brain injuries and the professional diagnosis of these possible injuries.

Likely you are surprised by the relatively recent research on *cognitive reserve* that can serve a person throughout their lifetime. For a healthy brain, we know that "use it or lose it" and "educate it" are good words of advice to people of all ages.

U.S. football and soccer provide examples of sports where concussions are common. In football, players wear carefully designed helmets that help to decrease the number concussions and the extent of damage that they produce. Some soccer leagues now require players to wear protective headgear.

Moreover, we know that bicycle helmets, motorcycle helmets, and automobile seatbelts help prevent brain injury in accidents. Still, many people resist the use of these safety measures. We attack this problem via a combination of education and laws.

You and Your Students

Select a topic from this chapter that seems particularly important to you and to the students you interact with. If you want a hint about what I would select, it is the combination of concussion and cognitive reserve.

For whatever topic you select, examine your own level of knowledge, and think about what the students you interact with know about the topic. Expand your knowledge on this topic, and decide what you think students should know about it. Then, to quote a famous Star Trek character, "Make it so."

Returning to my personal choice of concussion and cognitive reserve, you know that children often sustain a significant blow to the head and then hide it from adults. (My personal recollection is tilting back in my chair at school, tipping over, knocking myself dizzy when my head hit the concrete floor, and then pretending that I was just fine.) It is very important for children to learn to detect when they might have sustained a concussion, and that they should share this potential injury with a responsible adult.

I think all children should learn about cognitive reserve—along with the idea of "use it or lose it." This applies to both their physical and cognitive capabilities. Education/training of mind and body are cumulative, and serve a person for a lifetime. This statement reminds me of a military services ad that ran for many years, and included the line, "Be all you can be."

References and Resources for Chapter 9

Bird, S. (10/9/2013). The dangers for students addicted to brain Viagra: Drugs claimed to boost your intellect are sweeping universities—but at what cost? *Daily Mail.* Retrieved 7/20/2015 from http://www.dailymail.co.uk/health/article-2451586/More-students-turning-cognitive-enhancing-drug-Modafinil-hope-boosting-grades-job-prospects.html. Quoting from the article:

> With unemployment among graduates at record levels, more and more students are turning to 'cognitive enhancing drugs' in the hope of boosting their grades and therefore their job prospects.

The most popular of these drugs is Modafinil, a prescription-only stimulant used by doctors to treat patients suffering from the sleeping disorder narcolepsy.

Blazer, D., Yaffe, K., & Liverman, C., eds. (2015). Cognitive aging: Progress in understanding and opportunities for action. Retrieved 7/17/2015 from http://www.nap.edu/catalog/21693/cognitive-aging-progress-in-understanding-and-opportunities-for-action. Quoting from the website:

This Institute of Medicine (IOM) study focused on the public health dimensions of cognitive aging as separate from neurodegenerative diseases, such as Alzheimer's disease and other dementias. To accomplish its task, the IOM committee looked at cognitive aging through a broad lens and explored its implications for individuals, their families, and for society.

Gatlin, L. (1/12/2014). Caffeine has positive effect on memory, Johns Hopkins researchers say. (The article includes a 2-minute video.) *Hub.* Retrieved 5/20/2015 from http://hub.jhu.edu/2014/01/12/caffeine-enhances-memory. Quoting from the website:

Whether it's a mug full of fresh-brewed coffee, a cup of hot tea, or a can of soda, consuming caffeine is the energy boost of choice for millions who want to wake up or stay up. Now, researchers at Johns Hopkins University have found another use for the popular stimulant: memory enhancer.

Grant, R. (11/11/2010). Just can't get enough. (Includes a video by David Nutt by the same title.) (Video, 3:05.) Retrieved 7/17/2015 from http://blog.f1000.com/2010/11/11/just-cant-get-enough/. Quoting from the website:

[David Nutt talks about] his current work on brain imaging of addiction. He is interested in understanding the molecular underpinnings common to all forms of addiction, particularly how drugs reinforce addictive behaviour—why alcohol and heroin addicts [and gamblers] for example have trouble controlling their addiction.

Gregoire, C. (3/31/2015). Study reveals sad link between poverty and brain development. *The Huffington Post.* Retrieved 4/27/2015 from http://www.huffingtonpost.com/2015/04/17/how-to-sharpen-your-memory_n_7041374.html?utm_hp_ref=brain.

In brief summary, children growing up in affluence have bigger brains than children growing up in poverty. Quoting from the article: "The results revealed a strong positive association between family income and brain surface area, largely in those brain areas that are linked to skills instrumental in learning and academic achievement."

Grens, K. (7/22/2015). Cognitive decline more swift in women. *The Scientist.* Retrieved 5/23/2015 from http://www.the-scientist.com//?articles.view/articleNo/43592/title/Cognitive-Decline-More-Swift-in-Women/. Quoting from the article:

Mental agility in women deteriorates at twice the rate of that in men, according to a study of people with mild cognitive impairment.

Hamilton, J. (4/23/2014). Education may help insulate the brain against traumatic injury. *NPR.* Retrieved 7/20/2015 from http://www.npr.org/blogs/health/2014/04/23/306228476/education-may-help-insulate-the-brain-against-traumatic-injury. Quoting from the article:

… research on educational training suggests that it [cognitive reserve] involves strengthening the networks of brain cells involved in learning and memory, according to a commentary by Erin Bigler that accompanies the study. A stronger network may be better at repairing itself or adapting to damage, Bigler says.

Hussain, M., & Mehta, M. (January, 2011). Cognitive enhancement by drugs in health and disease. *Trends in Science Cognition.* Retrieved 7/23/2015 from http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3020278/. Quoting from the article:

Attempts to improve cognitive function in patients with brain disorders have become the focus of intensive research efforts. A recent emerging trend is the use of so-called cognitive enhancers by healthy individuals.

Layton, L. (1/16/2015). Majority of U.S. public school students are in poverty. *The Washington Post.* Retrieved 7/20/2015 from http://www.washingtonpost.com/local/education/majority-of-us-public-school-students-are-in-poverty/2015/01/15/df7171d0-9ce9-11e4-a7ee-526210d665b4_story.html. Quoting from the article:

For the first time in at least 50 years, a majority of U.S. public school students come from low-income families, according to a new analysis of 2013 federal data, a statistic that has profound implications for the nation.

Mantel, B. (9/17/2013). A good night's sleep scrubs your brain clean, researchers find. *NBC News.* Retrieved 11/11/2013 from http://www.nbcnews.com/health/good-nights-sleep-scrubs-your-brain-clean-researchers-find-8C11413186. Quoting from the article:

New research finds that a newly discovered system that flushes waste from your brain is mostly active during sleep.

Moursund, D. (12/14/2012). What I learned from learning to play a new computer game. *IAE Blog.* Retrieved 7/23/2015 from http://i-a-e.org/iae-blog/entry/what-i-learned-from-learning-to-play-a-new-computer-game.html.

DragonVale is a non-violent game suitable for a very broad range of children and adults. After nearly three weeks of "study" and practice, there were still more than 500,000 players who are ranked above me—indeed, I was ranked in the bottom third of all players.

Moursund, D., & Sylwester, R., eds. (April, 2011). Stress and education. Part 1: Introduction and overview. *IAE Newsletter.* Retrieved 7/19/2015 from http://i-a-e.org/newsletters/IAE-Newsletter-2011-64.html.

This series of four articles explores the psychology and biology of stress, with a special focus on the kinds of stress that negatively affect educational settings. Young people face a wide range of potential stressors—school being one of these.

National Sleep Foundation (n.d.). School start time and sleep. Retrieved 7/23/2015 from http://sleepfoundation.org/sleep-news/school-start-time-and-sleep. Quoting from the website:

"Over time, sleep deprivation leads to serious consequences for academic achievement, social behavior, and the health and safety of our nation's youth," the Congresswoman added. "We must encourage schools to push back their start times to at least 8:30 a.m. — a schedule more in tune with adolescents' biological sleep and wake patterns and more closely resembling the adult work day."

Pearl, R. (4/17/2014). A doctor's take on sports-related concussions. *Forbes.* Retrieved 5/19/2015 from http://www.forbes.com/sites/robertpearl/2014/04/17/a-doctors-take-on-sports-related-concussions/. Quoting from the article:

> "Simply put, a concussion is caused by a blow or jolt to the head or body that disrupts the function of the brain," Dr. Umphrey said. "The paradox of a concussion is that initial symptoms often appear quite mild but can lead to significant and lifelong impairment."

Sanders, R. (12/2/2008). EEGs show brain differences between poor and rich kids. *UC Berkley News.* Retrieved 12/25/08: http://berkeley.edu/news/media/releases/2008/12/02_cortex.shtml. Quoting from the article:

> University of California, Berkeley, researchers have shown for the first time that the brains of low-income children function differently from the brains of high-income kids.

Schulzke, E. (5/20/2014). Dumb and dumber? Teen marijuana use linked to lower IQ in later life. *National Deseret News*. Retrieved 7/17/2015 from http://national.deseretnews.com/article/1734/dumb-and-dumber-teen-marijuana-use-linked-to-lower-iq-in-later-life.html. Quoting from the article:

> [A long term study in New Zealand indicates that] those who regularly used marijuana as teens, … lost significant IQ points between their 13th and 38th years. Friends and associates also reported more cognitive problems among regular pot users, and even those who quit did not entirely regain all the ground they had lost in their youth.

Tucker, A., & Stern, Y. (6/1/2011). Cognitive reserve in aging. *US National Library of Medicine.* Retrieved 7/20/2015 from http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3135666/. Quoting from the paper:

> Cognitive reserve…refers to how flexibly and efficiently one can make use of available brain reserve. Standard proxies for cognitive reserve include education and IQ although this has expanded to include literacy, occupational attainment, engagement in leisure activities, and the integrity of social networks.

Vincent, J. (6/5/2014). Japanese 'robots with a heart' will care for the elderly and children. *The Independence.* Retrieved 7/23/2015 from http://www.independent.co.uk/life-style/gadgets-and-tech/japanese-robot-with-a-heart-will-care-for-the-elderly-and-children-9491819.html.

> The Japanese are world leaders in robotics. Quite a bit of their research and development efforts are being used to design and build robots that can provide care for needy people such as children and the elderly.

Chapter 10. Brain Science Applications to Math Education

> "To understand mathematics means to be able to do mathematics. And what does it mean doing mathematics? In the first place it means to be able to solve mathematical problems. For the higher aims about which I am now talking are some general tactics of problems—to have the right attitude for problems and to be able to attack all kinds of problems, not only very simple problems, which can be solved with the skills of the primary school, but more complicated problems of engineering, physics and so on, which will be further developed in the high school." (George Polya; Leading mathematician and math educator of the 20th century; 1887-1985.)

Stanislas Dehaene has written extensively about brain science and math education. Quoting from his article, Précis of "The Number Sense" (Dehaene, 2001):

> Four lines of evidence suggesting that **number sense constitutes a domain-specific biologically-determined ability** are reviewed: the presence of evolutionary precursors of arithmetic in animals; the early emergence of arithmetic competence in infants independently of other abilities, including language; the existence of a homology between the animal, infant, and human adult abilities for number processing; and the existence of a dedicated cerebral substrate. In adults of all cultures, lesions to the inferior parietal region can specifically impair number sense while leaving the knowledge of other cognitive domains intact. Furthermore, this region is demonstrably activated during number processing. I postulate that higher-level cultural developments in arithmetic emerge through the establishment of linkages between this core analogical representation (the " number line ") and other verbal and visual representations of number notations. The neural and cognitive organization of those representations can explain why some mathematical concepts are intuitive, while others are so difficult to grasp. **Thus, the ultimate foundations of mathematics rest on core representations that have been internalized in our brains through evolution.** [Bold added for emphasis.]

Brain Science and Mathematics Education

The general ideas and research results from brain science can be examined from the point of view of teaching and learning various specific disciplines. The first part of this chapter provides general background information applicable to the teaching and learning of any discipline of study. The remainder focuses specifically on brain science and the discipline of mathematics. An overview of math as an *invention* of humans versus math as a *discovery* of humans is provided in the video, The Great Math Mystery (NOVA, 4/15/2015).

Discipline of Study

People tend to use the term *discipline* when talking about a large and inclusive discipline of study, a sub-discipline, an interdisciplinary discipline, and so on. Each academic discipline or area of study can be defined by a combination of general things such as:

- The types of problems, tasks, and activities it addresses. For example, this book is about the discipline of brain science (cognitive neuroscience).
- Its accumulated accomplishments such as results, achievements, products, performances, scope, power, uses, impact on the societies of the world, and so on. For some disciplines, such as history and mathematics, the collected results go back many thousands of years.
- Its history, culture, and language, including notation and special vocabulary. The discipline of mathematics provides vocabulary and notation that is used in many other disciplines.
- Its methods of teaching, learning, assessment, and thinking. What it does to preserve and sustain its work and pass it on to future generations. Computer technology has changed both teaching and the storing/retrieving of information in each discipline. See David Moursund's article, The Teaching Machine Is Both Tool and Teacher, in chapter 4 of *Technology and Problem Solving in PreK-12 Education* (Moursund, 2015).
- Its tools, methodologies, and types of evidence and arguments used in solving problems, accomplishing tasks, and recording and sharing accumulated results. Computational Thinking (solving problems, designing systems, and understanding human behavior by drawing on concepts fundamental to computer science) is now important in almost every discipline of study. The "two brains are better than one" ideas discussed earlier in this book are facilitating a major change in every academic discipline of study.
- The knowledge and skills that separate and distinguish among: a) a novice; b) a person who has a personally useful level of competence; c) a reasonably competent person, employable in the discipline; d) an expert; and e) a world-class expert.

Definition of the Term, *Problem*

Here is a definition of *problem* that fits well in many different disciplines. **You** (personally) have a problem if the following four conditions are satisfied:

1. You have a clearly defined given initial situation.
2. You have a clearly defined goal (a desired end situation). Some writers talk about having multiple goals in a problem. However, such a multiple-goal situation can be broken down into a number of single-goal problems.
3. You have a clearly defined set of resources that may be applicable in helping you move from the given initial situation to the desired goal situation. These typically include some of your time, knowledge, and skills. Resources might include money, the Web, the telecommunication system, computers, friends, teachers, and so on. There may be specified limitations on resources, such as rules, regulations, guidelines, and time lines for what you are allowed to do in attempting to solve a particular problem.
4. You have some ownership—you are committed to using some of your own resources, such as your knowledge, skills, time, and energy, to achieve the desired final goal. That is, you have intrinsic motivation.

This definition is particularly important in education. All teachers struggle with keeping students "on task" and motivated. Research on intrinsic motivation and attention provides useful information to both teachers and their students.

The definition applies specifically to a *person* having a problem. Of course, we can talk about a school or school district having a problem, a company having a problem, and so on. This requires a somewhat different definition than our definition of a person having a problem.

Problem Solving

We routinely use our brains and aids to our brains to represent and solve problems. The term *problem solving* includes:

- **Question situations:** recognizing, posing, clarifying, and answering questions.
- **Problem situations:** recognizing, posing, clarifying, and then solving problems.
- **Task situations:** recognizing, posing, clarifying, and accomplishing tasks.
- **Decision situations:** recognizing, posing, clarifying, and making good decisions.

Problem solving includes using higher-order, critical, creative, wise, and foresightful thinking to do all of the above. Foresight—being able to think about possible consequences of planned actions—is a powerful aid to problem solving.

Humans have developed many powerful tools to aid in problem solving. The disciplines of reading, writing, and arithmetic (math) are so useful in representing and solving problems that they have become the "basics" in our school-based educational system. Computer technology builds on and enhances these "early" tools, but we have not yet fully integrated the use of this computer technology into our schools.

Polya's 6-step Strategy for Problem Solving

George Polya was one of the leading mathematicians of the 20th century, and he wrote extensively about problem solving. (See the quote at the beginning of this chapter.) One of his major contributions came from a careful analysis of good ways to approach and attempt to solve a challenging problem.

Polya's six-step strategy provides a general approach to attempting to solve a challenging problem. It is not a step-by-step procedure that is guaranteed to solve a problem, but is a strategy that can get you started in trying to solve any problem. Here is the strategy:

1. Understand the problem. Among other things, this includes working toward having a clearly defined problem. You need an initial understanding of the Givens, Resources, and Goal. This requires knowledge of the domain(s) of the problem, which could well be interdisciplinary.
2. Determine a plan of action. This is a thinking activity. What strategies will you apply? What resources will you use, how will you use them, in what order will you use them? Are the resources adequate to the task?
3. Think carefully about possible consequences of carrying out your plan of action. Place major emphasis on trying to anticipate undesirable outcomes. What new problems will be created? You may decide to stop working on the problem or return to step 1as a consequence of this thinking.
4. Carry out your plan of action in a reflective, thoughtful manner. This thinking may lead you to the conclusion that you need to return to one of the earlier steps. Reflective thinking leads to increased expertise and is an important learning strategy. Remember, there are many tools, such as computers, that can help in carrying out a plan of action.

5. Check to see if the desired goal has been achieved by carrying out your plan of action. Then do one of the following:
    a. If the problem has been solved, go to step 6.
    b. If the problem has not been solved and you are willing to devote more time and energy to it, make use of the knowledge and experience you have gained as you return to step 1 or step 2.
    c. Make a decision to stop working on the problem. This might be a temporary or a permanent decision. Keep in mind that the problem you are working on may not be solvable, or solving it may be beyond your current capabilities and resources.
6. Do a careful analysis of the steps you have carried out and the results you have achieved to see if you have created new, additional problems that need to be addressed. Reflect on what you have learned by solving the problem. Think about how your increased knowledge and skills can be used in other problem-solving situations. Work to increase your reflective intelligence! This reflection and metacognition is a key aspect of getting better at solving problems. While students tend to think that the goal in solving a problem assigned by the teacher is to "get a correct answer," the actual goal is to get better at solving problems.

Many people have found that this six-step strategy for problem solving is worth memorizing. As a teacher, you might decide that one of your goals in teaching problem solving is to have all your students memorize this strategy and practice it so that it becomes second nature. Students will need to practice it while solving problems in many different domains This will help to increase your students' expertise in solving problems.

Many of the steps in this six-step strategy require careful thinking. However, there are a steadily growing number of situations in which much of the work of step 4 can be carried out by a computer. Remember, a computer is a resource that is a valuable aid to problem solving. The person who is skilled at using a computer for this purpose may gain a significant advantage in problem solving, as compared to a person who lacks computer knowledge and skill.

The remainder of this chapter focuses specifically on the discipline of mathematics.

What Is Mathematics?

A longer version of the quote from George Polya that introduces this chapter, as well as considerable more discussion about What Is Mathematics, is available in David Moursund's article, What Is Mathematics? (Moursund, 2015). Quoting from this article:

> As an adult, you know a lot about math and you use your knowledge every day. Thus, if I ask you "What is mathematics?" you can give me an answer that fits with how you view and use math. You are empowered by your ability to use math in dealing with money, time, distance, area, weight, and other problem areas. Your insights into math and your uses of math help to guide you as you help children to learn math through their informal and formal education.
>
> …
>
> A different way to think about math is that it empowers people who seek to represent and solve a wide range of problems in different disciplines. Math is both a special language and a special approach to representing, thinking and reasoning about, and solving certain

kinds of problems. Because there has been such a large amount of research in math over the years, there is a huge accumulation of how to solve a wide variety of math problems. If a "real world" problem can be represented mathematically, this may be quite useful in solving the problem.

Here are three ideas that help to define goals of math education and empowering learners.

- **Math fluency** is being able to read, write, speak, listen, think, and understand communication in the language of mathematics. This is somewhat akin to developing fluency in a natural language such as English or Spanish. Rote memorization helps, but fluency comes from frequent, meaningful use of a language.
- **Math maturity** is being able to make effective use of the math that one has studied. It is the ability to recognize, represent, clarify, and solve math-related problems using the math one has studied. Thus, a fifth grade student can have a high or low level of math maturity relative to math content that one expects a typical fifth grader to have learned. Math maturity is increased by the demanding and challenging use of math in representing and solving problems—not only during math class time, but in each discipline one studies that makes use of math.
- A good math education prepares a student to make effective use of modern aids to gaining math fluency and math maturity, and using this knowledge and skills in one's personal and professional life.

Mathematics Education and Cognitive Neuroscience

My 6/7/2015 Google search of the term *brain science mathematics education* returned nearly 11 million results. A good summary of neuroscience findings relating to mathematics is provided in A Case for Neuroscience in Mathematics Education by Ana Susac and Sven Braeutigam (Susac & Braeutigam, 5/21/2014). Quoting from their paper:

> In summary, we are inclined to argue that neuroscience can eventually impact on mathematics education by providing hints as to **(a) what mathematics curriculum should be provided at which age, (b) which skills should be developed in parallel, and (c) how to reliably assess the effects of early diagnosis and interventions in the case of specific learning disabilities.** Research on the timing of maturation of brain areas involved in mathematical cognition appears particularly important as some economic models propose that earlier economic investment in education, i.e., in preschool programs, always lead to larger economic return than later investments (Cunha and Heckman, 2007). There is neuroscientific evidence, however, that indicates continuing development of executive functions throughout childhood and adolescence. Thus, educational policy makers should be aware of the current neuroscience findings when deciding on the timing of educational investment (Howard-Jones et al., 2012). [Bold added for emphasis.]

Reread item a) in the list quoted above. Math has a high level of abstractness. Our math education system has pushed the study of a first-year algebra course to lower grades—to well before students have reached formal operations on the Piagetian 4-stage scale. For a great many students, the level of abstraction and what it takes to "really understand" what they are trying to learn in a first-year algebra course is beyond their current level) stage) of cognitive development. They pass the course using a memorize-and-regurgitate approach.

Brian Butterworth

One of the important research works in this field is *The Mathematical Brain* by Brian Butterworth (1999). The following quotes are from three reviews of his book that are summarized on his website (Butterworth, 1999).

> So you think you're bad at maths? Meet Charles, he has a normal IQ and a university degree yet has problems telling whether 5 is bigger than 3. And what about Signora Gaddi, an Italian woman who hears and sees normally but, following a stroke, is deaf and blind to all numbers above 4? (Alison Motluk, interviewer.)
>
> [Continuing the Signora Gaddi story:]
>
> A cheerful English voice, crisp and elegant, asked her the question again. "How many coins do you have there, Signora?"
>
> Signora Gaddi stared at the coins in her hand for a long time, and then looked up to smile apologetically at the doctor. It was a soft smile, warm, but tenuous and sad. The corners of her lips trembled delicately when she tried to explain the inexplicable: she knew that there were more than four, but she could not imagine how many. Were there eight? Or ten? Or some other strange number, whose name hung heavily on her tongue and could not be uttered?
>
> "It's all right, Signora. There are six coins." The doctor's voice was kind; he understood. He knew of other people like Signora Gaddi, people who had little or no sense of numbers. These people were not simply bad at math, nor were they poorly educated. The clinical terms are **acalculia**, for people like Signora Gaddi who lost her sense of numbers after a stroke, and **dyscalculia** for people who were born without numbers. But clinical terms don't go very far towards describing the people who lead lives almost completely devoid of numbers. [Bold added for emphasis.] (Ashish Ranpura, interviewer.)
>
> **Brian Butterworth:** Well, some people like, for example, Piaget, argued that really mathematics was no more than an extension of logic and the mathematician Keith Devlin in a recent book called the "Maths Gene" [*The Math Gene: How Mathematical Thinking Evolved*], has argued that maths is nothing more than an extension of language. Now modern scientific approaches to how the brain deals with numbers and other aspects of mathematics show that really there are separate parts of the brain that deal with maths on the one hand, deal with reasoning on the other hand and deal with language on the third hand.
>
> So there is evidence that there is independence in the brain. Of course it doesn't mean that there's functional independence. Clearly you learn most maths through language. But once you've learnt it, does it get stored with other things that you've learnt through language or does it get stored somewhere else? One of the things that we've been working on—and we work on these things entirely opportunistically, it depends who comes into the clinic—is about whether reading words, reading numbers and recently, reading music all use the same brain circuits or whether they use separate ones. (Robyn Williams, interviewer.)

Dongjo Shin

In 2014, Dongjo Shin taught a course at the University of Georgia titled Neuroscience in Mathematics Education (Shin, Fall, 2014). Quoting from the course materials:

> Neuroscience is literally the scientific study of the nervous system. Unlike the traditional perspective, neuroscience is an interdisciplinary science that collaborates with other fields like linguistics, mathematics, psychology, and computer science as well as science, medicine, and so on. More specifically, Campbell (2010) mentions educational neuroscience as a new area of educational research that can be regarded as "an applied cognitive neuroscience, insofar as the tools, methods, and predominantly mechanistic and functionalist frameworks of cognitive neuroscience are applied to educational problems" (p. 315). Neuroscience perspectives on human learning have drawn increasing interest among researchers in education. Particularly, researchers in science and mathematics education have emphasized the utility of integrating a neuroscience or cognitive–science perspective into science and mathematics learning (Anderson, Love, & Tsai, 2014). Until quite recently, however, little research exists in mathematics education exploring some of the possible implications of neuroscience for mathematics education (Campbell, 2010). I would like to focus this paper on **a) why neuroscientific methodology is meaningful in mathematics education,** b) how neuroscientific methodologies have been used in mathematics education, and c) what further research studies of mathematics learning are possible using neuroscientific methodologies. [Bold added for emphasis.]

As the examples given above help illustrate, there is now substantial ongoing research on neuroscience and the teaching and learning of mathematics. Translating this progress into the curriculum is a slow process!

Innate Math Skills

Within any specific area of human endeavor, some people are born with considerably more innate potential than are others. Math provides a good area to study this situation. Are there significant brain differences between people who become good at math and those who struggle with math and perhaps make little progress in learning this discipline?

We have a great deal of research on students with low math-learning capabilities. Roughly, students in the bottom five percent of math-learning capabilities "peak out" at about the fourth to fifth grade in our current math education curriculum. That is, their rate of forgetting what they have learned and their rate of learning or relearning balance each other out at about this grade level, and they remain at that level year after year as they continue in school and continue to try to learn math. For more information see my *IAE-pedia* article, Improving Math Education (Moursund, 2015).

One way that researchers use to better understand innate math skills is to look at animals. What are the math capabilities and limitations of some non-human brains? Basic Math in Monkeys and College Students by Jessica Cantlon and Elizabeth Brannon is a good example of this type of study (Cantlon & Brannon, 2007). Quoting from the article:

> Adult humans possess a sophisticated repertoire of mathematical faculties. Many of these capacities are rooted in symbolic language and are therefore unlikely to be shared with nonhuman animals. However, a subset of these skills is shared with other animals, and this set is considered a cognitive vestige of our common evolutionary history. Current evidence indicates that humans and nonhuman animals share a core set of abilities for representing and comparing approximate numerosities nonverbally; however, it remains unclear whether nonhuman animals can perform approximate mental arithmetic. Here we show that monkeys can mentally add the numerical values of two sets of objects and

> choose a visual array that roughly corresponds to the arithmetic sum of these two sets. Furthermore, monkeys' performance during these calculations adheres to the same pattern as humans tested on the same nonverbal addition task. **Our data demonstrate that nonverbal arithmetic is not unique to humans but is instead part of an evolutionarily primitive system for mathematical thinking shared by monkeys.**
>
> …
>
> The fact that humans and nonhuman animals represent numerical values nonverbally using a common cognitive process is well established. Both human and nonhuman animals can nonverbally estimate the numerical values of arrays of dots or sequences of tones and determine which of two sets is numerically larger or smaller. When adult humans and nonhuman animals make approximate numerical comparisons, their performance is similarly constrained by the ratio between numerical values (i.e., Weber's law). Thus, discrete symbols such as number words and Arabic numerals are not the only route to numerical concepts; both human and nonhuman animals can represent number approximately, in a nonverbal code. [Bold added for emphasis.]

Research about the human brain has identified an Approximate Number System (ANS). Quoting from the Wikipedia:

> The approximate number system (ANS) is a cognitive system that supports the estimation of the magnitude of a group without relying on language or symbols.… Beginning in early infancy, the ANS allows an individual to detect differences in magnitude between groups. The precision of the ANS improves throughout childhood development and reaches a final adult level of approximately 15% accuracy, meaning an adult could distinguish 100 items versus 115 items without counting. The ANS plays a crucial role in development of other numerical abilities, such as the concept of exact number and simple arithmetic. The precision level of a child's ANS has been shown to predict subsequent mathematical achievement in school.

Natalie Angier's article, Gut Instinct's Surprising Role in Math, provides a down-to-earth introduction to ANS (Angier, 9/15/2008). Quoting from her article:

> One research team has found that how readily people rally their approximate number sense is linked over time to success in even the most advanced and abstruse mathematics courses. Other scientists have shown that preschool children are remarkably good at approximating the impact of adding to or subtracting from large groups of items but are poor at translating the approximate into the specific. Taken together, the new research suggests that math teachers might do well to emphasize the power of the ballpark figure, to focus less on arithmetic precision and more on general reckoning.

A free ANS self-assessment test is available at Test your ANS. In this test, a collection of blue and yellow dots is flashed on the screen for 0.2 seconds. Your goal is to decide whether there are more blue than yellow dots, or vice versa. You do this over and over again, with different sets of dots.

A Research Mathematician's Mind

Amongst mathematicians, the mathematician Jacque Hadamard is well known both for his research results in mathematics and for his 1945 book, *An Essay on the Psychology of Invention in the Mathematical Field* (Hadamard, 1945). Quoting from his book:

> It may be useful to keep in mind that mathematical invention is but a case of invention in general, a process which can take place in several domains, whether it be in science, literature, in art or also technology.
>
> Modern philosophers even say more. They have perceived that intelligence is perpetual and constant invention, that life is perpetual invention. As Ribot says, "Invention in Fine Arts or Sciences is but a special case. In practical life, in mechanical, military, industrial, commercial inventions, in, religious, social, political institutions, the human mind has spent and used as much imagination as anywhere else.

Peter Liljedahjl's 2004 paper, Mathematical Discovery: Hadamard Resurrected, presents a more recent analysis of Hadamard's ideas (Liljedahjl, 2004). Quoting from the paper:

> Hadamard's treatment of the subject of invention at the crossroads of mathematics and psychology was an entertaining, and sometimes humorous, look at the eccentric nature of mathematicians and their ritualistic practices. **His work is an extensive exploration and extended argument for the existence of unconscious mental processes.** To summarize, Hadamard took the ideas that Poincaré had posed and, borrowing a conceptual framework for the characterization of the creative process in general, turned them into a stage theory. **This theory still stands as the most viable and reasonable description of the process of mathematical invention.** In what follows I present this theory, referenced not only to Hadamard and Poincaré, but also to some of the many researchers whose work has informed and verified different aspects of the theory.
>
> …
>
> The phenomenon of mathematical invention, although marked by sudden illumination, consists of four separate stages stretched out over time, of which illumination is but one part. **These stages are initiation, incubation, illumination, and verification** (Hadamard, 1945). The first of these stages, t**he initiation phase, consists of deliberate and conscious work.** This would constitute a person's voluntary, and seemingly fruitless, engagement with a problem and be characterized by an attempt to solve the problem by trolling through a repertoire of past experiences (Bruner, 1964; Schön, 1987). This is an important part of the inventive process because it creates the tension of unresolved effort that sets up the conditions necessary for the ensuing emotional release at the moment of illumination (Barnes, 2000; Davis & Hersh, 1980; Feynman, 1999; Hadamard, 1945; Poincaré, 1952; Rota, 1997).
>
> **Following the initiation stage the solver, unable to come to a solution stops working on the problem at a conscious level (Dewey, 1933) and begins to work on it at an unconscious level** (Hadamard, 1945; Poincaré, 1952). This is referred to as the incubation stage of the inventive process and it is inextricably linked to the conscious and intentional effort that precedes it.
>
> There is another remark to be made about the conditions of this unconscious work: it is possible, and of a certainty it is only fruitful, if it is on the one hand preceded and on the other hand followed by a period of conscious work. These sudden inspirations never happen except after some days of voluntary effort which has appeared absolutely fruitless and whence nothing good seems to have come (Poincaré, 1952, p. 56). [Bold added for emphasis.]

What Peter Liljedahl is stressing is that mathematical invention occurs at a subconscious level. I first experienced this phenomenon when I was a doctoral student and I was working on a quite difficult problem. Key ideas for solving the problem came to me while I was asleep. I awoke, thought about the ideas that had come to me, and they worked! So, I am a believer of Liljedahl's four-stage theory.

Final Remarks

Children easily gain oral fluency in the language or languages of their household and immediate neighborhood. This ability to do so is innate to their brains.

Our brains have some innate math capabilities, and these can develop to a useful level without the benefit of formal schooling. They do this as part of their learning of their natural language(s). However, over thousands of years humans have developed math far beyond the level of simple enumeration and calculation. As this steadily growing body of math evolved, so did its importance and uses in many different disciplines.

Thus, today's children face the challenge of learning math at a far higher and deeper level than did our ancestors. We have ample evidence that our current math education system is not able to achieve a level of success that many people would like to see.

The combination of progress in cognitive neuroscience and in the development of computers provides us with research and tools that can greatly improve our math education system. However, our overall educational system is structured in such a way that there is considerable resistance to the types of major changes needed to implement our growing knowledge of the two brains (human and computer). Thus, math education will be a vibrant area for research, development, and improved implementation for a great many years to come.

You and Your Students

This chapter contains a substantial amount of information important to both teachers of math and to their students. It can be divided into two major categories:

1. Information about problem solving that is applicable to any discipline of study. You want your students to become better at recognizing, representing, and solving the problems they encounter throughout their lives. A unifying theme is that two brains (human and computer) are better than one. As a teacher, you want your students to learn to know about the capabilities and limitations of each effectively use both types brains .
2. Each discipline of study presents its own challenges to both teaching and learning. You want your students to learn how they best learn math. You want them to gain increased insight into how their brain works as it learns and uses math, and how to help their brain become better at these two tasks. You want them to learn pitfalls of using only a rote memory approach to learning math.

In both of the above, these goals should be made clear to students at an appropriate cognitive development level.

References and Resources for Chapter 9

Angier, N. (9/15/2008). Gut instinct's surprising role in math. *The New York Times.* Retrieved 10/6/2013 from http://www.nytimes.com/2008/09/16/science/16angi.html?_r=0. Quoting from the article:

> Rats, pigeons, monkeys, babies — all can tell more from fewer, abundant from stingy. An approximate number sense is essential to brute survival: how else can a bird find the best patch of berries, or two baboons know better than to pick a fight with a gang of six?

Butterworth, B. (1999). *The mathematical brain.* London: Macmillan.

Both research and individuals' stories in the book provide evidence that there is a small brain area above one's left ear that deals with quantity. If damaged by nature or nurture, the results are devastating to a person's ability to deal with quantity.

The interviews quoted in the text were retrieved 6/12/2015 from http://www.mathematicalbrain.com/int.html. The full interviews are referenced under the name of each interviewer: Motluk, Ranpura, and Williams.

Cantlon, J.F., & Brannon, E.M. (2007). Basic math in monkeys and college students. *PLoS Biol*ogy. Retrieved 12/19/07 from http://journals.plos.org/plosbiology/article?id=10.1371/journal.pbio.0050328. Quoting from the article:

> …like humans, nonhuman animals possess the ability to estimate and compare numerical values nonverbally. We asked whether humans and nonhuman animals also share a capacity for nonverbal arithmetic.

Dehaene, S. (2001) Précis of "The number sense." Retrieved 7/5/2015 from http://www.unicog.org/publications/Dehaene_PrecisNumberSense.pdf. Quoting from the article:

> "Number sense" is a short-hand for our ability to quickly understand, approximate, and manipulate numerical quantities. My hypothesis is that number sense rests on cerebral circuits that have evolved specifically for the purpose of representing basic arithmetic knowledge.

Devlin, K. (2001). *The math gene: How mathematical thinking evolved and why numbers are like gossip.* New York: Basic.

Hadamard, J. (1945). *An essay on the psychology of invention in the mathematical fields.* New York: Dover. Retrieved 6/7/2015 from *https://archive.org/details/eassayonthepsych006281mbp*.

This book was written by a research mathematician and is primarily oriented to students and other people who have studied and done mathematics at the graduate student level.

Liljedahjl, P. (2004). Mathematical discovery: Hadamard resurrected. Retrieved 6/12/2015 from http://www.emis.de/proceedings/PME28/RR/RR116_Liljedahl.pdf. Quoting from the article:

> What is the genesis of mathematical creation? What mechanisms govern the act of mathematical discovery? This "is a problem which should intensely interest the psychologist. It is the activity in which the human mind seems to take the least from the outside world, in which it acts or seems to act only of itself and on itself" (Poincaré, 1952, p. 46).

Motluk, A. (7/3/1999). *The mathematical brain* (interview). *New Scientist.* Retrieved 6/12/2015 from http://www.newscientist.com/article/mg16321935.000-true-grit.html#.VX4jhuczWE4.

Moursund, D. (2015). Improving math education. *IAE-pedia.* Retrieved 6/11/2015 from http://iae-pedia.org/Improving_Math_Education.

An extensive exploration of ways to improve our math education system. Includes : What is math?; The problems of change; Six types of math education goals; The "I can't do math" phenomenon; and Ideas for improving math education.

Moursund, D. (2015). *Technology and problem solving: PreK-12 education for adult life, careers, and further education.* Eugene, OR: Information Age Education. Download the PDF file from http://i-a-e.org/downloads/free-ebooks-by-dave-moursund/267-technology-and-problem-solving-in-prek-12-education-1.html. Download the Microsoft Word file from http://i-a-e.org/downloads/free-ebooks-by-dave-moursund/266-technology-and-problem-solving-in-prek-12-education.html. Web document: http://iae-pedia.org/Technology_and_Problem_Solving.

Moursund, D. (2015). What is mathematics? *IAE-pedia.* Retrieved 6/11/2015 from http://iae-pedia.org/What_is_Mathematics.

NOVA (4/15/2015). The great math mystery. (Video, 53:10.) *PBS Video.* Retrieved 6/24/2015 from http://video.pbs.org/video/2365464997/.

This program explores the question of whether mathematics is something that humans have invented or something that humans have discovered. For example, we can think of inventing the concept of integers 1, 2, 3, etc., but discovering relationships, patterns, and properties of these numbers—for example, prime numbers or Fibonacci numbers. Ideas from brain science are interspersed though the video.

Ranpura, A. (July 5, 2006). A conversation with Brian Butterworth (interview). *Brain Connection.* Retrieved 6/14/2015 from http://brainconnection.brainhq.com/2006/07/05/a-conversation-with-brian-butterworth/.

Shin, D. (Fall, 2014). Neuroscience in mathematics education. University of Georgia course. Retrieved 6/7/2015 from http://jwilson.coe.uga.edu/EMAT7050/Papers2014/Dshin.EMAT%207050%202nd%20paper%20(Revised).pdf . Quoting from the document:

Then why are many educational researchers focusing on neuroscience recently? What can we obtain from neuroscientific methodologies for the research studies in mathematics education? The discipline of neuroscience, compared to educational research, is a very young and so it is unreasonable to assume that such an innovative discipline will quickly resolve essential issues and problems in mathematics education.

Susac, A., & Braeutigam, S. (5/21/2014). A case for neuroscience in mathematics education. *Frontiers in human neuroscience.* Retrieved 6/14/2015 from http://www.ncbi.nlm.nih.gov/pmc/articles/PMC4033123/. Quoting from the document:

Mathematics lies at the heart of science and technology impacting on the economic performance of societies since ancient times (OECD, 2010). At the level of individuals too, the development of mathematical proficiency appears correlated with individual development and career prospects across a wide range of professions (RAND Mathematics Study Panel and Loewenberg Ball, 2003)

Williams, R. (November 18, 2000). Mathematics gene (interview). *The Science Show.* Retrieved 6/12/2015 from http://www.abc.net.au/radionational/programs/scienceshow/mathematics-gene/3477070.

Videos for *Brain Science for Educators and Parents*

Preface

Gallwey, T.W. (1970). Inner game of tennis. (Video, 12:14.) Retrieved 6/21/2015 from https://www.youtube.com/watch?v=ieb1lmm9xHk. Quoting from the website:

> In 1970 W. Timothy Gallwey author of "Inner Game of Tennis," demonstrates how to teach tennis without teaching. A woman who doesn't know how to play tennis at all, can play within 10 minutes.

Merzenich, M. (2004). Growing evidence of brain plasticity. (Video, 23:07.) *TED Talks.* Retrieved 6/11/2015 from http://www.ted.com/talks/michael_merzenich_on_the_elastic_brain?language=en. Quoting from the website:

> Neuroscientist Michael Merzenich looks at one of the secrets of the brain's incredible power: its ability to actively re-wire itself. He's researching ways to harness the brain's plasticity to enhance our skills and recover lost function.

Schultz, L. (June, 2015). The surprisingly logical minds of babies. (Video, 20:18.) *TED Talks*. Retrieved 7/16/2015 from http://www.ted.com/talks/laura_schulz_the_surprisingly_logical_minds_of_babies/transcript?language=en.

> An enlightening and amusing introduction to the amazing capabilities of the minds of babies. Laura Schultz argues that pre-toddlers and toddlers have mind capabilities that exceed the artificial intelligence of current computers—and the computers she expects to see for many years to come.

Chapter 1: Introduction to Brain Science

Allan Institute (2015). Allan Institute for Brain Science: Fueling discovery. (Video, 5:37.) Retrieved 4/27/2015 from http://alleninstitute.org/news-events/videos/.

> The non-profit Allan Institute was founded by Paul Allan, one of the founders of Microsoft. The Institute carries out research on fundamental, challenging brain science topics, and shares its results with researchers throughout the world.

Kanwisher, N. (2014). Nancy's brain talks. (Videos, various lengths.) Retrieved 4/23/2015 from http://nancysbraintalks.mit.edu. Quoting from the website:

> Welcome! I'm a professor at MIT who uses a brain imaging method called fMRI to study the human brain. This site contains short talks on the different scientific methods we can use to study the human mind and brain, and some of the cool things we have learned so far. You do not need any background in the field to understand the talks. For an overall introduction, watch my [March, 2014] TED talk.

Chapter 2: Executive Functions and Memory

NOVA (2005). Mirror neurons. (Video, 14:00.) *NOVA Science Now.* Retrieved 6/12/2015 from http://www.pbs.org/wgbh/nova/body/mirror-neurons.html. Quoting from the website:

> According to provocative discoveries in brain imaging, inside our heads we constantly "act out" and imitate whatever activity we're observing. As this video reveals, our so-

called "mirror neurons" help us understand the actions of others and prime us to imitate what we see.

Posner, M. (2009). Implications of cognitive neuroscience for education. (Video, 19:58.) *GoCognitive.* Retrieved 7/5/2015 from http://www.gocognitive.net/video/michael-posner-implications-cognitive-neuroscience-education. Quoting from the website:

> Dr. Michael Posner describes how general principles of brain development and brain function have been applied to educational practice. Dr. Posner specifically highlights the improved understanding of the cognitive processes in reading and executive attentional control as examples of how modern cognitive neuroscience can inform educational approaches.

Chapter 3: The Changing Brain

Blakemore, S. (June, 2012). The mysterious workings of the adolescent brain. (Video, 14:26.) *TED Talks*. Retrieved 5/10/2015 from http://www.ted.com/talks/sarah_jayne_blakemore_the_mysterious_workings_of_the_adolescent_brain. Quoting from the website:

> Why do teenagers seem so much more impulsive, so much less self-aware than grown-ups? Cognitive neuroscientist Sarah-Jayne Blakemore compares the prefrontal cortex in adolescents to that of adults, to show us how typically "teenage" behavior is caused by the growing and developing brain.

Merzenich, M. (2004). Growing evidence of brain plasticity. (Video, 23:07.) *TED Talks.* Retrieved 5/9/2015 from http://www.ted.com/talks/michael_merzenich_on_the_elastic_brain?language=en.

> In this video, neuroscientist Michael Merzenich looks at one of the secrets of the brain's incredible power: its ability to actively re-wire itself. He's researching ways to harness the brain's plasticity to enhance our skills and recover lost function.

OSU Department of Neurology (n.d.). OSU researchers design self-test for memory disorders: [video title is] Pen-and-paper test may help spot Alzheimer's early. (Video, 1:43.) Ohio State University Wexner Medical Center. Retrieved 6/15/2015 from http://neurology.osu.edu/sagetest.html. Quoting from the website:

> The handwritten self-assessment, which can take less than 15 minutes to complete, is a reliable tool for evaluating cognitive abilities.

PBS FRONTLINE (2002). Inside the teenage brain. (Video, 60:00.) *PBS FRONTLINE.* Retrieved 5/10/2015 from http://www.pbs.org/wgbh/pages/frontline/shows/teenbrain/view/. Quoting from the website:

> In "Inside the Teenage Brain," FRONTLINE chronicles how scientists are exploring the recesses of the brain and finding some new explanations for why adolescents behave the way they do. These discoveries could change the way we parent, teach, or perhaps even understand our teenagers.

Chapter 4: Three Brains: Human, Reading/Writing, and Computer

Eagleman, D. (March, 2015). Can we create new senses for humans? (Video, 20:34.) *TED Talks.* Retrieved 4/27/2015 from

https://www.ted.com/talks/david_eagleman_can_we_create_new_senses_for_humans?language=en. Quoting from the website:

> As humans, we can perceive less than a ten-trillionth of all light waves. "Our experience of reality," says neuroscientist David Eagleman, "is constrained by our biology." He wants to change that. His research into our brain processes has led him to create new interfaces — such as a sensory vest — to take in previously unseen information about the world around us.

Kish, D. (March, 2015). How I use sonar to navigate the world. (Video, 13:03.) *TED Talks.* Retrieved 4/27/2015 from http://www.ted.com/talks/daniel_kish_how_i_use_sonar_to_navigate_the_world. Quoting from the website:

> Daniel Kish has been blind since he was 13 months old, but has learned to "see" using a form of echolocation. He clicks his tongue and sends out flashes of sound that bounce off surfaces in the environment and return to him, helping him to construct an understanding of the space around him.

Leuthardt, E. (11/1/2014). Mind, powered. (Video, 5:01.) *The Scientist*. Retrieved 5/17/2015 from http://www.the-scientist.com//?articles.view/articleNo/41367/title/Mind--Powered/.

In this short video, neuroscientist Eric Leuthardt shows examples of mind-controlled human-computer interfaces.

Chapter 5: Intelligence

Annenberg (2012). Neuroscience & classroom: Making connections. (42 videos, varying lengths.) *Annenberg Learner.* Retrieved 5/31/2015 from http://www.learner.org/resources/series214.html.

Designed as a video course for grades K-12 teachers, school counselors, and college teachers, the 42 videos vary in length and often are accompanied by course guide, online text, website, and other resources.

Flynn, J. (9/29/2013). James Flynn: Why our IQ levels are higher than our grandparents. (Video, 18:40.) *TED Talks*. Retrieved 5/29/2015 from http://www.ted.com/talks/james_flynn_why_our_iq_levels_are_higher_than_our_grandparents.html. Quoting from the website:

> [Flynn] argues that our brains perform much better than in the past because we are providing them with mental tools—tools we store in our brains and that our brains use in addressing problems and tasks. That is, in the nature versus nurture debate, it isn't that nature has provided us with much better brains in the past century or so. Instead, nurture has made our brains much more capable in the types of performance areas measured by IQ tests.

Gardner, H. (October 8, 2014). Beyond wit & grit: Howard Gardner's '8 for 8'. (Video, 7:43.) Harvard Graduate School of Education. *YouTube*. Retrieved 6/15/2015 from https://www.youtube.com/watch?v=vnqWZdcC8AE.

This short video presents Howard Gardner's ideas on effective use of one's wits (Multiple Intelligences) and grit (courage and resolve; strength of character; perseverance) to be a good, responsible person.

Goleman, D. (11/2/2013). Daniel Goleman on focus: The secret to high performance and fulfillment. (Video, 1:18:18.) Retrieved 6/19/2015 from https://www.youtube.com/watch?v=HTfYv3IEOqM.

Attention today is under siege—most of us face an overwhelming collection of demands on our attention. Attention between a pair or group of people is being seriously damaged by communication technology. Also discusses Flow, stress, emotion, and so on.

Goleman, D. 8/3/2007). Daniel Goleman: Authors@Google. (Video, 55:52.) Retrieved 6/19/2015 from https://youtu.be/-hoo_dIOP8k. Quoting from the website:

> Daniel Goleman discusses his book *Social Intelligence: The New Science of Human Relationships* as a part of the Authors@Google series. This event took place on August 3, 2007 at Google headquarters in Mountain View, CA.

Chapter 6: Creativity, Curiosity, Commitment, and Critical Thinking

Csikszentmihalyi, M. (February, 2004). Flow, the secret to happiness. (Video, 18:55.) *TED Talks.* Retrieved 5/29/2015 from http://www.ted.com/talks/mihaly_csikszentmihalyi_on_flow. Quoting from the website:

> Mihaly Csikszentmihalyi asks, "What makes a life worth living?" Noting that money cannot make us happy, he looks to those who find pleasure and lasting satisfaction in activities that bring about a state of "flow."

de Posada, J. (February, 2009). Don't eat the marshmallow. (Video. 5:58.) *TED Talks.* Retrieved 6/11/2015 from http://www.ted.com/talks/joachim_de_posada_says_don_t_eat_the_marshmallow_yet?language=en. Quoting from the website:

> In this short talk from TED U, Joachim de Posada shares a landmark experiment on delayed gratification — and how it can predict future success. With priceless video of kids trying their hardest not to eat the marshmallow.

Duckworth, A. (April, 2013). The key to success? Grit. (Video, 6:12.) *TED Talks*. Retrieved 5/27/2015 from http://www.ted.com/talks/angela_lee_duckworth_the_key_to_success_grit?language=en#t-172495. Quoting from the website:

> At the University of Pennsylvania, Angela Lee Duckworth studies intangible concepts such as self-control and grit to determine how they might predict both academic and professional success.

Lyon, A. (4/20/2014). Teaching grit: How to help students overcome inner obstacles. (Video, 6:20.) *Edutopia.* Retrieved 5/27/2015 from http://www.edutopia.org/blog/grit-help-students-overcome-inner-obstacles-vicki-zakrzewski.

Watch teacher Amy Lyon help her 5th graders learn valuable lessons about how to deal with frustration and distractions as they set and work toward long-term goals.

Robinson, K. (February, 2006). How schools kill creativity. (Video, 19:24.) *TED Talks.* Retrieved 5/25/2015 from http://www.ted.com/talks/ken_robinson_says_schools_kill_creativity. Quoting from the website:

> Creativity expert Sir Ken Robinson challenges the way we're educating our children. He champions a radical rethink of our school systems, to cultivate creativity and acknowledge multiple types of intelligence.

TED Talks (n.d.). Creativity. (Video series.) *TED Talks.* Retrieved 5/24/2015 from https://www.ted.com/topics/creativity.
This site provides links to more than 30 *TED Talks* related to creativity.

- 8 talks: Where do ideas come from?
- 6 talks: The creative spark.
- 11 talks: What is success?
- 8 talks: The Remix.

UCLA (2015). Bjork Learning & Forgetting Lab. (8 short videos). Retrieved 5/29/2015 from http://bjorklab.psych.ucla.edu/research.html#rif. Quoting from the website:

> The primary goal of this research, which is funded by the James S. McDonnell foundation, is to promote learning and memory performance within educational contexts through the investigation of principles in cognitive psychology. Studies address issues of transfer-appropriate and material-appropriate processing between encoding and retrieval.

Chapter 7: Consciousness, Dreaming, Free Will, Hypnosis, Sleep Learning, and Meditation

Cuddy, A. (June, 2012). Body language shapes who you are. (Video, 21:02.) *TED Talks.* Retrieved 6/18/2015 from http://www.ted.com/talks/amy_cuddy_your_body_language_shapes_who_you_are?language=en. Quoting from the website:

> Body language affects how others see us, but it may also change how we see ourselves. Social psychologist Amy Cuddy shows how "power posing" — standing in a posture of confidence, even when we don't feel confident — **can affect testosterone and cortisol levels in the brain**, and might even have an impact on our chances for success. [Bold added for emphasis.]

Damasio, A. (March, 2011). The quest to understand consciousness. (Video, 18:42.) *TED Talks*. Retrieved 6/25/2015 from http://www.ted.com/talks/antonio_damasio_the_quest_to_understand_consciousness?language=en. Quoting from the website:

> Every morning we wake up and regain consciousness — that is a marvelous fact — but what exactly is it that we regain? Neuroscientist Antonio Damasio uses this simple question to give us a glimpse into how our brains create our sense of self.

Dennett, D. (February, 2003). The illusion of consciousness. (Video, 21:48.) *TED Talks.* Retrieved 6/25/2015 from

http://www.ted.com/talks/dan_dennett_on_our_consciousness?language=en. Quoting from the website:

> Philosopher Dan Dennett makes a compelling argument that not only don't we understand our own consciousness, but that half the time our brains are actively fooling us. [He] argues that human consciousness and free will are the result of physical processes.

Firestein, S. (9/24/2013). The pursuit of ignorance with Stuart Firestein. (Video, 18:33.) *TED Talks.* Retrieved 7/5/201 from http://tedtalkspsychology.com/the-pursuit-of-ignorance-with-stuart-firestein/. Quoting from the website:

> One of the secrets that Firestein shares is that scientific research is often a hit or miss affair with some use of the scientific method combined with a good deal of luck. You might be surprised to learn that as potential scientists, we should value "high quality ignorance" as well as perceived knowledge.

NOVA (9/15/2012). What are dreams? (Video, 55:05.) *PBS.org.* Retrieved 6/19/2015 from https://www.youtube.com/watch?v=i539ynXmh-c.

Presents a number of examples of dreams, information from and/or about people who have done research on dreams, and some insights from dream researchers.

NOVA (Multiple dates.) Body + brain. *PBS.org.* Retrieved 6/19/2015 from http://www.pbs.org/wgbh/nova/body/.

Provides access to 15 episodes. Includes How smart can we get?, How does the brain work?, and Cracking the code of life.

Searle, J. (July, 2013). Our shared condition–consciousness. (Video, 14:59.) *TED Talks.* Retrieved 6/25/2015 from https://www.ted.com/talks/john_searle_our_shared_condition_consciousness?language=en. Quoting from the website:

> Philosopher John Searle lays out the case for studying human consciousness — and systematically shoots down some of the common objections to taking it seriously. As we learn more about the brain processes that cause awareness, accepting that consciousness is a biological phenomenon is an important first step.

Wilson, E.O. (April, 2012). Advice to young scientists. (Video, 14:56.) *TED Talks.* Retrieved 7/5/2015 from https://www.ted.com/talks/e_o_wilson_advice_to_young_scientists. Quoting from the website:

> "The world needs you, badly," begins celebrated biologist E.O. Wilson in his letter to a young scientist. Previewing his upcoming book, he gives advice collected from a lifetime of experience — reminding us that wonder and creativity are the center of the scientific life.

Chapter 8: Brain Disorders

Chung, W. (April, 2014). Autism—what we know (and what we don't know yet). (Video, 16:31.) *TED Talks.* Retrieved 5/16/2015 from http://www.ted.com/talks/wendy_chung_autism_what_we_know_and_what_we_don_t_know_yet/transcript?language=en. Quoting from her talk:

"Why?" "Why?" is a question that parents ask me all the time. "Why did my child develop autism?" As a pediatrician, as a geneticist, as a researcher, we try and address that question.

Grandin, T. (February, 2010). Temple Grandin: The world needs all kinds of minds. (Video, 19:43.) *TED Talks.* Retrieved 7/13/2015 from http://www.ted.com/talks/temple_grandin_the_world_needs_all_kinds_of_minds.html. Quoting from the website:

> Temple Grandin, diagnosed with autism as a child, talks about how her mind works—sharing her ability to "think in pictures," which helps her solve problems that neurotypical brains might miss. She makes the case that the world needs people on the autism spectrum: visual thinkers, pattern thinkers, verbal thinkers, and all kinds of smart geeky kids.

Kanwisher, K. (March, 2014). A neural portrait of the human mind. (Video, 17:40.) *TED Talks.* Retrieved 7/11/2015 from http://www.ted.com/talks/nancy_kanwisher_the_brain_is_a_swiss_army_knife. Quoting from the website:

> Brain imaging pioneer Nancy Kanwisher, who uses fMRI scans to see activity in brain regions (often her own), shares what she and her colleagues have learned: The brain is made up of both highly specialized components and general-purpose "machinery." Another surprise: There's so much left to learn.

Shankardass, A. (November, 2009). A second opinion on developmental disorders. (Video, 9:01.) *TED Talks India.* Retrieved 7/13/2015 from https://www.ted.com/talks/aditi_shankardass_a_second_opinion_on_learning_disorders?language=en. Quoting from the website:

> Developmental disorders in children are typically diagnosed by observing behavior, but Aditi Shankardass suggests we should be looking directly at brains. She explains how one EEG technique has revealed mistaken diagnoses and transformed children's lives.

Silberman, S. (March, 2015). The forgotten history of autism. (Video, 13:48.) *TED Talks.* Retrieved 7/5/2015 from https://www.ted.com/talks/steve_silberman_the_forgotten_history_of_autism?language=en. Quoting from the website:

> Decades ago, few pediatricians had heard of autism. In 1975, 1 in 5,000 kids was estimated to have it. Today, 1 in 68 is on the autism spectrum. What caused this steep rise?

Sousa, D. (1/28/2013). ADHD—A case for over diagnosis? (Video, 18:24.) *TEDx Talks.* Retrieved 7/12/2015 from https://www.youtube.com/watch?v=ygKNRnz7q5o.

A major component of this presentation is a summary of causes of ADHD-like behavior that leads to a misdiagnosis of ADHD. Sousa argues that many children receive behavior modification medication when their symptoms can be treated without the use of drugs.

Chapter 9: Brain Damage

Gatlin, L. (1/12/2014). Caffeine has positive effect on memory, Johns Hopkins researchers say. (The article includes a 2-minute video.) *Hub.* Retrieved 5/20/2015 from http://hub.jhu.edu/2014/01/12/caffeine-enhances-memory. Quoting from the website:

> Whether it's a mug full of fresh-brewed coffee, a cup of hot tea, or a can of soda, consuming caffeine is the energy boost of choice for millions who want to wake up or stay up. Now, researchers at Johns Hopkins University have found another use for the popular stimulant: memory enhancer.

Grant, R. (11/11/2010). Just can't get enough. (Includes a video by David Nutt by the same title.) (Video, 3:05.) Retrieved 7/17/2015 from http://blog.f1000.com/2010/11/11/just-cant-get-enough/. Quoting from the website:

> [David Nutt talks about] his current work on brain imaging of addiction. He is interested in understanding the molecular underpinnings common to all forms of addiction, particularly how drugs reinforce addictive behaviour—why alcohol and heroin addicts [and gamblers] for example have trouble controlling their addiction.

Chapter 10: Brain Science Applications to Math Education

NOVA (4/15/2015). The great math mystery. (Video, 53:10.) *PBS Video.* Retrieved 6/24/2015 from http://video.pbs.org/video/2365464997/.

> This program explores the question of whether mathematics is something that humans have invented or something that humans have discovered. For example, we can think of inventing the concept of integers 1, 2, 3, etc., but discovering relationships, patterns, and properties of these numbers—for example, prime numbers or Fibonacci numbers. Ideas from brain science are interspersed though the video.