Presented June 4, 2016 at the New Mexico STEM Symposium, Albuquerque, NM

Brain Science and Classroom Education

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My objective is two-pronged

- **Provide a framework for effectively incorporating neuroscience into K-12 education**
- **Apply neuroscience research to improve education outcomes**

Neuroscience is important

- No field of science more directly bears upon everyday experiences




- One of the most active fields of science today

- Maladies of the brain and nervous system affect over a billion people worldwide

What is neuroscience?

Neuroscience = Brain Science

It is the study of the brain, and its

- **function**
- **development**
- **abnormalities/diseases**

Also, the application of knowledge of the brain to improve everyday life and create new technologies

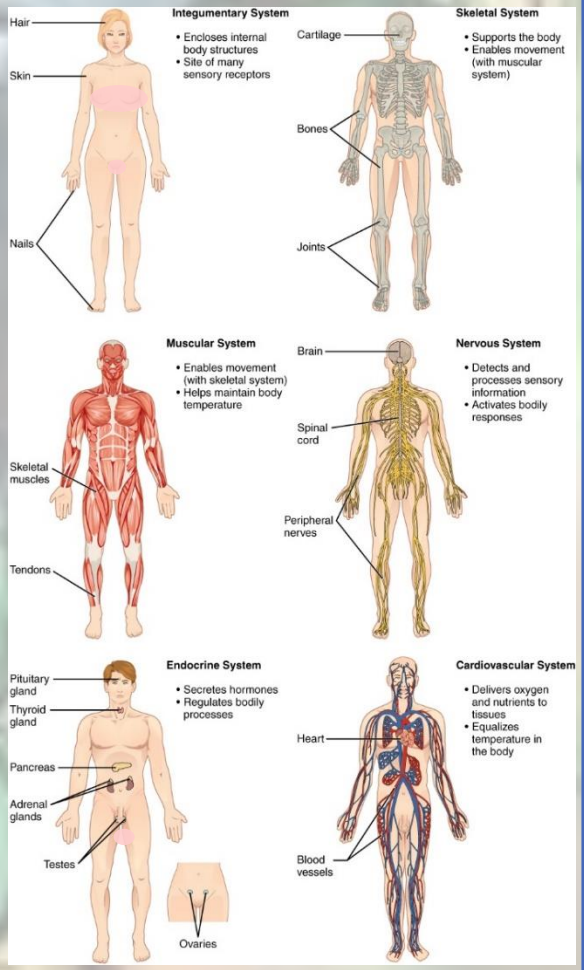
Instruction may be organized around basic principles

There are twelve basic principles every student should understand

Principle 1: The brain is one system within a system of systems

There is a two-way interaction between the brain and other biological systems of the body

- **K-5th – understand idea of system interactions and that brain functions better/worse with overall health**
- **6th-8th – cite specific two-way interactions**
- **9th-12th – hypothesize effects of two-way interactions**



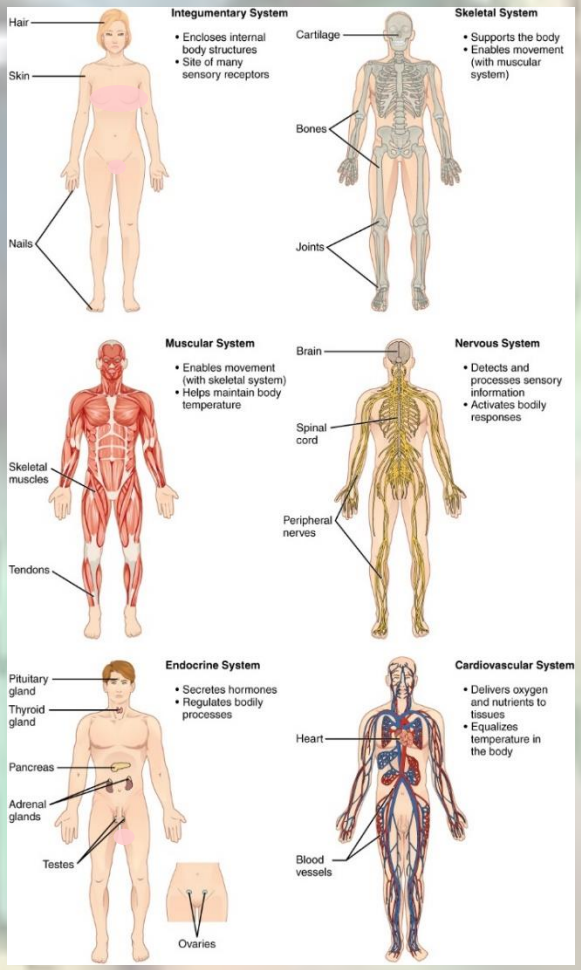
Principle 1: The brain is one system within a system of systems

There is a two-way interaction between the brain and other biological systems of the body

Next Generation Science Education Standards Core Ideas

PS2.C: Stability and Instability in Physical Systems

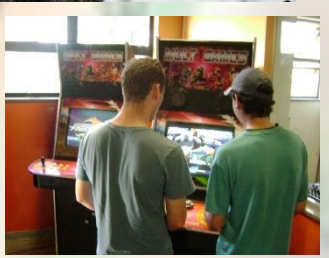
LS1.A: Structure and Function



Principle 2: The brain is a biological engine

To function properly, the brain must be adequately fueled and maintained

- **K-5th – know the brain's five needs: food and nutrients, water, oxygen, sleep & stimulation**
- **6th-8th – hypothesize and explain effects of deficiencies in the five needs**
- **9th-12th – basic understanding of underlying mechanisms**



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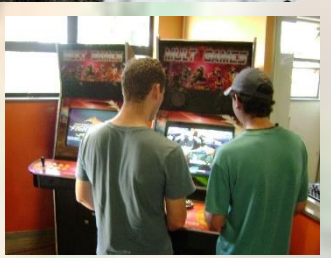


<u>Next Generation Science Education Standards Core Ideas</u>

PS2.C: Stability and Instability in Physical Systems

PS3.A: Definitions of Energy

PS3.D Energy in Chemical Processes and Everyday Life

LS1.C: Organization for Matter and Energy Flow in Organisms

Principle 3: Experience continuously shapes the brain

The brain is "plastic," continually changing throughout life

- **K-5th – identify the skills being developed through own activities**
- **6th-8th – explain changes that occur with practice and compare/contrast skills for different activities**
- **9th-12th – understand relationship between skills and brain functions (i.e., specialization of function)**

Principle 3: Experience continuously shapes the brain

The brain is “plastic,” continually changing throughout life

Next Generation Science Education Standards Core Ideas

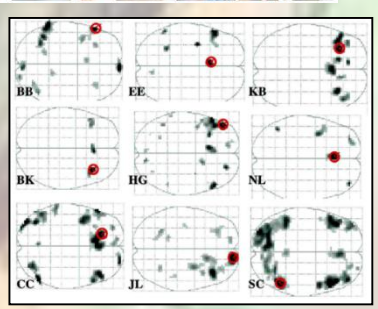
LS1.B: Growth and Development of Organisms

LS1.D: Information Processing

LS3.B: Variation of Traits

Principle 4: Every brain is different

As with the body, genes have the instructions for building a basic brain, yet every brain is different



- **K-5th – describe own strengths and weaknesses & other differences (e.g., personality)**
- **6th-8th – extrapolate to performance or preference for activities/occupations, understand relationship to learning**
- **9th-12th – relate differences to functional differences in brain circuits**

Principle 4: Every brain is different

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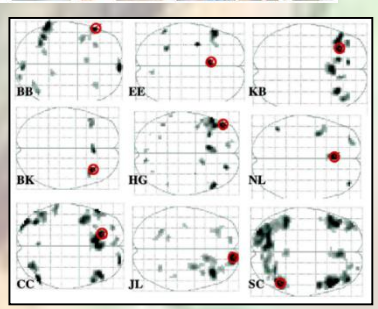


Next Generation Science Education Standards Core Ideas

LS1.B: Growth and Development of Organisms

LS1.D: Information Processing

LS3.A: Inheritance of Traits

LS3.B: Variation of Traits

LS4.B: Natural Selection

LS4.C: Adaptation

Principle 5: Brain performance fluctuates over time

Over the course of a day, and with activities (e.g., fatigue), individual performance capabilities vary

- **K-5th – recognize when at their best and what makes them better/worse**
- **6th-8th – distinguish intrinsic (e.g., sleep-wake cycles) and acute (e.g., fatigue) performance factors**
- **9th-12th – weigh factors and predict performance outcomes, relate variability to brain function**

Principle 5: Brain performance fluctuates over time

Over the coarse of a day, and with activities (e.g., fatigue), individual performance capabilities vary

<u>Next Generation Science Education Standards Core Ideas</u>

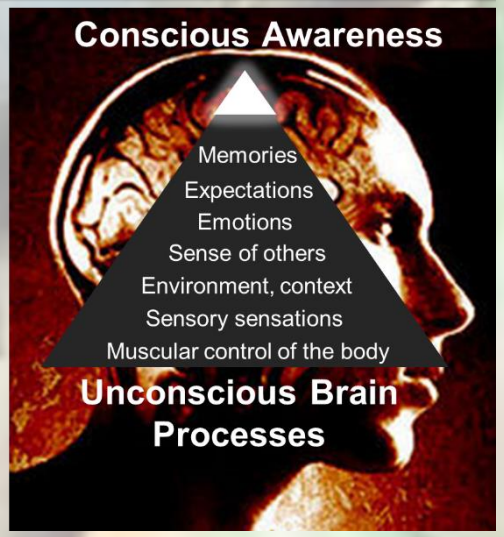
PS2.C: Stability and Instability in Physical Systems

LS1.A: Structure and Function

Principle 6: Brains mostly operate at an unconscious level

We have conscious awareness of a small fraction of what goes on in the brain

- **K-5th – understand distinction between conscious and unconscious brain processes**
- **6th-8th – cite examples and effects of unconscious influences**
- **9th-12th – explain mechanisms by which unconscious brain processes affect behavior, decisions, etc.**



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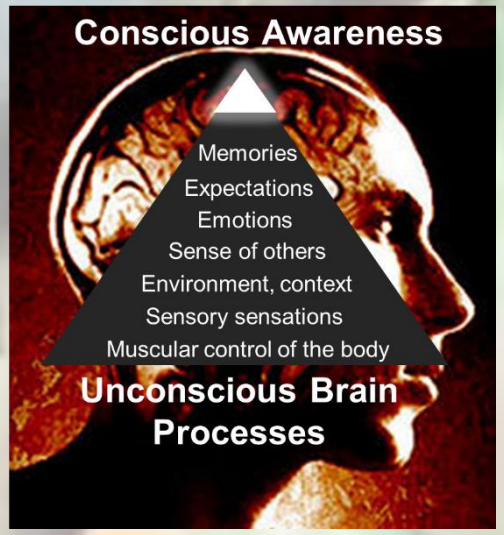


<u>Next Generation Science Education Standards Core Ideas</u>

LS1.D: Information Processing

Principle 7: Attention may be focused inward or outward

Under certain circumstances the brain naturally shifts awareness from the external to the internal

- **K-5th – understand the distinction between internal and external awareness**
- **6th-8th – explain factors that may make one shift attention inward or outward**
- **9th-12th – understand mechanisms for internal and external awareness**

Principle 7: Attention may be focused inward or outward

Under certain circumstances the brain naturally shifts awareness from the external to the internal

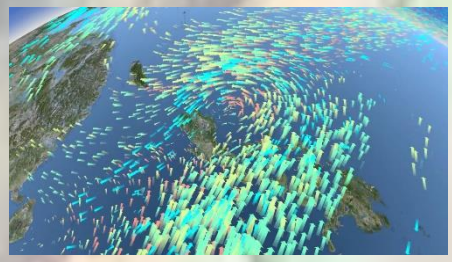
<u>Next Generation Science Education Standards Core Ideas</u>

LS1.D: Information Processing

Principle 8: The brain senses and responds to patterns

The brain detects regularities and reacts to violations of the resulting expectations

- **K-5th – describe patterns involving different senses, as well as language**
- **6th-8th – breakdown everyday situations with regard to formation of patterns and violations of expectations**
- **9th-12th – explain brain mechanisms that account for pattern detection and monitoring expectations**



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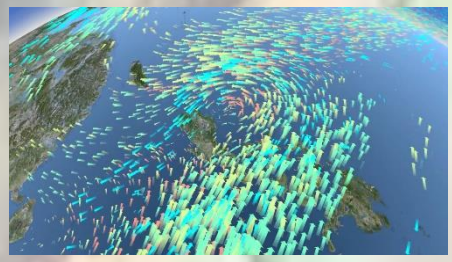


<u>Next Generation Science Education Standards Core Ideas</u>

PS2.C: Stability and Instability in Physical Systems

LS1.D: Information Processing

Principle 9: Memory relies on association and elaboration

Cues and associations enable the brain to recall specific memories

- **K-5th – know techniques for improving memory performance**
- **6th-8th – explain mechanisms that account for success and failure in memory performance**
- **9th-12th – understand brain processes for memory formation and retrieval, and associated failures**

Principle 9: Memory relies on association and elaboration

Cues and associations enable the brain to recall specific memories

Next Generation Science Education Standards Core Ideas

LS1.D: Information Processing

Principle 10: Brains constantly appraise the world around us

Brain reward systems seek to maximize positive experience while avoiding displeasure

- **K-5th – understand use of reward and punishment to shape behavior**
- **6th-8th – effectively apply behavior shaping principles and recognize their use to influence behavior**
- **9th-12th – understand basic functions of brain reward systems**

Principle 10: Brains constantly appraise the world around us

Brain reward systems seek to maximize positive experience while avoiding displeasure

<u>Next Generation Science Education Standards Core Ideas</u>

LS1.D: Information Processing

LS2.D: Social Interactions and Group Behavior

Principle 11: Brains would be useless without emotions

There is a broad range of emotions that serve to motivate and steer behavior

- **K-5th – identify different emotions the situations in which they arise and their physical expression**
- **6th-8th – predict effects of emotional responses on performance**
- **9th-12th – explain brain processes for emotion regulation, and positive and negative effects on performance**

Principle 11: Brains would be useless without emotions

There is a broad range of emotions that serve to motivate and steer behavior

<u>Next Generation Science Education Standards Core Ideas</u>

LS1.D: Information Processing

LS2.D: Social Interactions and Group Behavior

Principle 12: Our brains are uniquely sensitive to others

The brain has an inherent capacity to sense and respond, often mimicking, the behavior of others

- **K-5th – appreciate the ability to infer thoughts and emotions of others**
- **6th-8th – explain key aspects of cognitive and emotional states that affect team/group interactions**
- **9th-12th – explain brain mechanisms engaged in team/group interactions**

Principle 12: Our brains are uniquely sensitive to others

The brain has an inherent capacity to sense and respond, often mimicking, the behavior of others

<u>Next Generation Science Education Standards Core Ideas</u>

LS1.D: Information Processing

LS2.D: Social Interactions and Group Behavior

Context for addressing Next Gen Physical Science Core Ideas

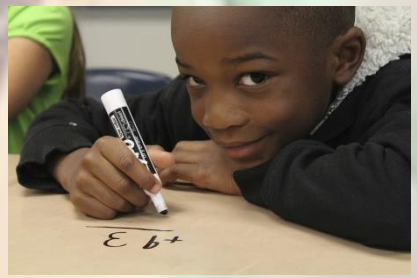
	Basic Principles	Cellular Neuroscience	Measurement Techniques	Perceptual Processes	Concussion
PS1.A: Structure and Properties of Matter		X			
PS1. B Chemical Reactions		X			
PS1.C: Nuclear Processes			X		
PS2.A: Forces and Interactions				X	
PS2.B: Types of Interactions		X	X		
PS2.C: Stability and Instability in Physical Systems	X	X			
PS3.A: Definitions of Energy	X	X		X	
PS3.B: Conservation of Energy and Energy Transfer			X	X	X
PS3.C: Relationship between Energy and Forces			X		X
PS3.D Energy in Chemical Processes and Everyday Life	X	X			
PS4.A: Wave Properties			X	X	
PS4.B: Electromagnetic Radiation				X	
PS4.C: Information Technologies and Instrumentation			X		

Context for addressing Next Gen Life Science Core Ideas

	Basic Principles	Cellular Neuroscience	Perceptual Processes	Concussion	Social Neuroscience	Comparative Neuroscience
LS1.A: Structure and Function	X	X	X	X		
LS1.B: Growth and Development of Organisms	X	X				
LS1.C: Organization for Matter and Energy Flow in Organisms	X	X				
LS1.D: Information Processing	X		X		X	X
LS2.A: Interdependent relationships within ecosystems					X	X
LS2.B: Cycles of Matter and Energy Transfer within Ecosystems					X	X
LS2.C: Ecosystem Dynamics, Functioning and Resilience						X
LS2.D: Social Interactions and Group Behavior	X				X	X
LS3.A: Inheritance of Traits	X	X				
LS3.B: Variation of Traits	X	X				X
LS4.A: Evidence of Common Ancestry and Diversity		X				X
LS4.B: Natural Selection	X					X
LS4.C: Adaptation	X					X
LS4.D: Biodiversity and Humans						

Basic principles provide foundation for Metacognitive Training

Metacognitive training involves developing a generalized ability to use the brain more effectively, producing across-the-board improvements in school performance



NOTE: See citations of supporting research in backup slides

Basic principles provide a foundation for Metacognitive Training

Metacognitive training teaches skills and practices that involve using the brain better

Principle 5: Brain performance fluctuates over time

Metacognitive Practice – organize work to do hardest tasks when brain is at its best (i.e., Demand Scheduling)

- **Sense the capacity, or lack of capacity, of the brain to do work**
- **Anticipate when the brain is at its best and at its worst**
- **Predict depletion from mental/physical expenditure**
- **Predict recovery from mental/physical expenditure**
- **Estimate demand imposed by tasks or activities**

There are many Metacognitive Practices

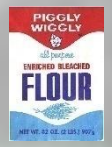
- Gap Filling
- Demand Assessment
- Demand Scheduling
- Tactical Learning
- Social Facilitation
- Enhanced Interaction
- Outcome/Progress Monitoring
- Performance Calibration
- Capability Tuning
- Emotion Regulation

NOTE: Complete list of practices and skills are in backup slides

Metacognitive Training begins with learning skills

The Metacognitive practice of Gap Filling involves filling gaps in knowledge or skills

How to bake a cake





This requires several skills:

- **Assess what you know**

- **Assess how well do you know it**

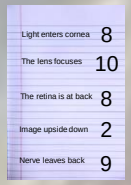
- **Identify what you do not know**


- **Determine what you need to know**

Specific skills may be practiced during various lessons

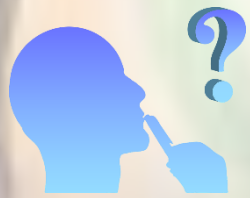
How does the human eye work?

Create a series of statements and a drawing that shows what you know



Give every statement a score between 1-10 for how certain you are it is correct

List five things that do not know, but seem important



Create questions that would increase certainty and improve explanation

It's getting easier to do Neuroscience in the K-12 classroom

Low-cost equipment is now available from various sources

FLORIDA RESEARCH INSTRUMENTS

EEG – Starter Kit

~ $115

NeuroSky
Body and Mind. Quantified.

MindWave EEG

~ $100

OPENBCI

EEG Headset

~ $250

EMOTIV

INSIGHT EEG

~ $300

NeuLog

Galvanic Skin Response

~ $150

BACKYARD BRAINS

Electrophysiological Measurement Kits

~ $100-$250

It's getting easier to do Neuroscience in the K-12 classroom

There are online resources with reusable content and activities.

Brain Hackers Association –library of reusable content, including classroom activities
http://www.brainhackers.net/

Backyard Brains – detailed instructions, including background for numerous laboratory experiments
https://backyardbrains.com/

Neuroscience for Kids – library of activities, experiments and reusable content
http://faculty.washington.edu/chudler/neurok.html

Allen Institute for Brain Science – detailed atlases of mouse and human brains
http://www.brain-map.org/

There is no need to fear students doing human studies

Research using human and animal test subjects may require review and approval.

UNM STEM-H Center *for* Outreach, Research & Education

Offers human and animal studies review and approval

NOTE: students must plan time to complete paperwork and receive approval

Students are encouraged to participate in events

NeuroExpoABQ

April 24th, 10:00 – 2:00

New Mexico Museum of Natural History and Science

Free with paid admission

Featuring interactive demonstrations in

- Brain and behavioral phenomenon
- Technologies for measuring brain function
- Virtual and augmented reality
- Brain-controlled robots and games
- Brain science-inspired art

Brain Hackers Association

30 YEARS New Mexico Museum of Natural History & Science

new mexico technology council NMTC

Sandia National Laboratories LOCKHEED MARTIN

THE UNIVERSITY of NEW MEXICO

THE MIND RESEARCH NETWORK

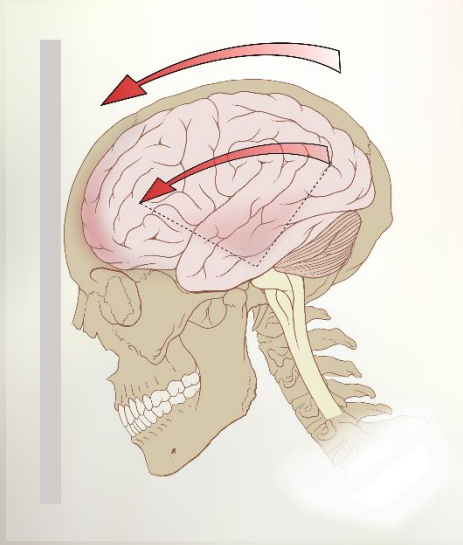
NeuroSleuth Face-Off

Team competition using mouse brain connectivity atlas to decipher brain networks

For more information, email info@brainhackers.net

Opportunity to provide awareness concerning critical topics

Concussion and Brain Injury



Coping with Stress

Mental Illness

Review of the main points and final thoughts

- An opportunity exists to enhance STEM through incorporation of Neuroscience
  - Make STEM relevant to everyday life
  - Reduce gender gap
  - Low-hanging fruit
- Twelve basic principles provide foundation for addressing Neuroscience
- Metacognitive training builds upon Neuroscience and has far-reaching benefits
- Brain Hackers Association supports teachers and schools through programs and activities

Back-Up Slides

Citations for Metacognitive Training

Young, A., & Fry, J. (2012). Metacognitive awareness and academic achievement in college students. *Journal of the Scholarship of Teaching and Learning*, *8*(2), 1-10.

- Found correlation between awareness of metacognitive skills and cumulative GPA and end-of-course grades for college students

Aleven, V. A., & Koedinger, K. R. (2002). An effective metacognitive strategy: Learning by doing and explaining with a computer-based Cognitive Tutor. *Cognitive science*, *26*(2), 147-179.

- Students who employed self-explanation demonstrated superior understanding

Thiede, K. W., Anderson, M., & Therriault, D. (2003). Accuracy of metacognitive monitoring affects learning of texts. *Journal of educational psychology*, *95*(1), 66.

- Metacognitive monitoring during study produced greater reading comprehension and better associated test scores

Hartwig, M. K., & Dunlosky, J. (2012). Study strategies of college students: Are self-testing and scheduling related to achievement?. *Psychonomic Bulletin & Review*, *19*(1), 126-134.

- Self-testing and study scheduling correlated with higher grade-point averages

Citations for Metacognitive Training

Kramarski, B., & Mevarech, Z. R. (2003). Enhancing mathematical reasoning in the classroom: The effects of cooperative learning and metacognitive training. *American Educational Research Journal*, *40*(1), 281-310.

- Students provided metacognitive training in a cooperative learning setting outperformed students not receiving training and in independent learning conditions for mathematical reasoning

Schmidt, A. M., & Ford, J. K. (2003). Learning within a learner control training environment: The interactive effects of goal orientation and metacognitive instruction on learning outcomes. *Personnel Psychology*, *56*(2), 405-429.

- Reported levels of metacognitive activity correlated with performance on a skill-based measure of computer skills

Kramarski, B., Mevarech, Z. R., & Lieberman, A. (2001). Effects of multilevel versus unilevel metacognitive training on mathematical reasoning. *The Journal of Educational Research*, *94*(5), 292-300.

- Metacognitive training correlated with superior math performance

Metacognitive practices and skills

Gap Filling - recognize discrepancies between existing knowledge/skills, and essential or desired knowledge/skills

- Assess what you know
- Evaluate confidence in what you know
- Identify what you do not know
- Determine what you need to know

Demand Assessment – assess demands and optimally allocate attention

- Distinguish what is more or less important
- Identify need for focused attention
- Recognize distractions
- Assess own level of distractibility
- Allocate attention optimally

Metacognitive practices and skills

Demand Scheduling – optimally manage resources with regard to task or other demands

- Assess own capacity for mental exertion
- Predict future capacity/diminished capacity for mental exertion
- Anticipate ability to recover from diminished capacity
- Estimate demands for mental exertion
- Match capacity to demands for mental exertion

Tactical Learning – optimally manage resources for learning and memory

- Distinguish what need to remember from what can be forgotten
- Assess how difficult it will be to remember items
- Select a learning strategy, including need for elaboration
- Identify cues to facilitate later memory recall
- Evaluate goodness of learning and compensate appropriately

Metacognitive practices and skills

Social Facilitation – leverage social interactions to enhance learning, memory and performance

- Assess what others know and do not know
- Generate questions that promote enhanced understanding
- Assess what others believe you know and do not know and correct discrepancies
- Express own knowledge verbally, in writing, in drawing, etc.
- Verbalize thought processes in manner that others understand

Enhanced Interaction – employ practices that promote more effective and efficient social interactions

- Assess the interruptability of others and interrupt accordingly
- Assess the comprehension of others and resolve discrepancies
- Communicate own comprehension, or failure to comprehend
- Recognize shared knowledge and experiences
- Make connections to shared knowledge and experiences

Metacognitive practices and skills

Outcome/Progress Monitoring – maintain awareness of progress toward objectives and take corrective actions when needed

- Imagine desired outcome and progression to that outcome
- Assess current progress relative to desired progression
- Recognize when current coarse of action is insufficient to achieve desired outcomes in allotted time

Performance Calibration – calibrate performance with regard to speed and accuracy to task demands

- Assess need for speed relative to accuracy
- Recognize own orientation toward speed versus accuracy
- Identify discrepancies between own orientation toward speed versus accuracy and needs of task
- Calibrate performance to the need for speed versus accuracy

Metacognitive practices and skills

Emotion Regulation – recognize and manage positive and negative influences of emotions on performance

- Appreciate the range of positive and negative emotional states
- Recognize ongoing and anticipate future emotional states
- Recognize when own emotional state is negatively or positively affecting performance
- Assess tolerance for negative emotional states
- Substitute positive emotional states for negative emotional states

Capability Tuning – assess and manage one's own capabilities

- Assess own strengths and weaknesses relative to meaningful characteristics
- Recognize discrepancies between ongoing and future demands and own capabilities
- Monitor progress in resolving discrepancies between demands and capabilities