What abilities and skills will you need to be successful in the 21st century?
What will it likely take to be successful in the 21st century?

1) Creativity

• Coming up with new ideas, hypotheses and Inventions.

• If one way of solving a problem isn’t working, how else might we succeed here? Can we think outside the box to come up with a way of attacking this no one else has considered before?
2) Flexibility

- Seeing opportunities and seizing them: I was planning to do X, but an amazing opportunity has arisen to do Y, do I have the flexibility to take advantage of serendipity?
- My opinion was X, but now that I see this new information, I’m able to change my opinion.
- Being able & willing to change course when it seems you were wrong
An example of poor cognitive flexibility:

When one door closes, another door opens; but we often look so long and so regretfully upon the closed door, that we do not see the ones which open for us.

- Alexander Graham Bell
3) Self-control

Having the self-control to resist temptations and not act impulsively -- be able to:

• think before you speak or act -- give a considered response instead of an impulsive one
• not over-indulge or indulge in the wrong things
• resist saying something socially inappropriate (or hurtful)
• resist ‘tit for tat’ (hurting someone because that person hurt you)
• resist jumping to an interpretation of what something meant or why it was done
4) Discipline / Perseverance

Having the discipline to stay on task…

- seeing it through to completion despite unexpected problems, some aspects being boring or perhaps frustratingly difficult, & tempted by lots of things far more fun

- continuing to work at something though the reward may be a long time in coming
Evidence shows that discipline accounts for over twice as much variation in final grades as does IQ, even in college.

(Duckworth & Seligman, 2005)
Question: How do creativity, flexibility, self-control, & discipline map onto the 3 core EFs?
ALL of the above are “Executive Functions” or rely on them
The 3 core Executive Functions are:

• **Cognitive Flexibility**
  (including being able to switch perspectives & see things in a new light)

• **Inhibitory Control**
  (which includes self-control & discipline)

• **Working Memory**

Higher-order Executive Functions are:

• Problem-solving
• Reasoning
• Planning
Inhibitory control includes being able to:

1. Stay focused despite distraction (Selective or Focused Attention)
2. Stay on task (& complete task) though tempted not to (Discipline)
3. Inhibit acting impulsively & instead make a more considered response (not putting your foot in your mouth, not hitting, not drinking too much, dieting) (Self-Control)
Inhibition can be critical in helping students to wait before speaking or acting so that they think before they act instead of impulsively reacting, and so that they resist the temptation to answer quickly, instead taking the time they need.
THE DAY-NIGHT TASK
(Gerstadt, Hong, & Diamond, 1994)

Semantically conflicting labels

“Day”

“Night”

Requires holding 2 rules in mind, and inhibiting saying what the images really represent, saying the opposite instead.
DITTY

Experimenter sings a little ditty

♫ think about the answer, don’t tell me ♫

before the child responds.

Imposes time between presentation of stimulus
and response to make children take the time
they need to ‘compute’ the answer
Percentage of Correct Responses by 4-Year-Old Children on the Song and Standard Conditions of the Day-Night Task

- **Song**: 89%
- **Standard**: 56%

Chance: ~90%
VIDEO
Inhibition allows us a measure of control over our attention and our actions, rather than simply being controlled by external stimuli, our emotions, or old habits of mind or behavior.

Thus it helps make it possible for us to change & to **CHOOSE** how we react and how we behave rather than being “unthinking” creatures of habit. It doesn’t make overriding habits or automatic responses easy, but it creates the possibility.
Children with less inhibitory control (i.e., children who were less persistent, more impulsive, and had poorer attention regulation) as adults 30 years later have...

- worse health
- earn less
- and commit more crimes

than those with better inhibitory control as young children, controlling for IQ, gender, social class, & home lives & family circumstances growing up across diverse measures of inhibitory control.
That’s based on a study of 1,000 children born in the same city in the same year followed for 32 years with a 96% retention rate.

by Terrie Moffitt et al. (2011)

_Peacekeeping of the Nat’l Academy of Sci._

Interventions that achieve even small improvements in [inhibitory control] for individuals could shift the entire distribution of outcomes in a beneficial direction and yield large improvements in health, wealth, and crime rate for a nation.”
Nowhere in their data, did Moffitt et al. find any hint of a discontinuity or cutoff between those clinically diagnosed with a self-control impairment (like ADHD) and everyone else. For wealth, health, and crime the gradients are linear and continuous.
Those ADULTS, who as children had worse inhibitory control, have worse HEALTH

Moffitt et al., 2011
What does that imply about disorders like ADHD?
(b) Working Memory:
Holding information in mind and mentally working with it
Working memory is critical for making sense of anything that unfolds over time, for that always requires holding in mind what happened earlier & relating that to what is happening now.
• relating one idea to another
• relating what you read (or learned / heard) earlier to what you are reading (learning / hearing) now
• mental math calculations
• understanding cause and effect
• remembering multi-step instructions & executing them in the correct order
Reasoning would not be possible without working memory, for reasoning requires holding bits of information in mind and seeing how they relate. Working memory enables us to consider the past and possible future in making plans and decisions.
What some people call “working memory” could also be termed:

Keeping your **ATTENTION** focused on specific mental contents while mentally working with them.
Empirically, selective attention and working memory are very tightly linked.

The same prefrontal system that helps us selectively attend to stimuli in our environment also helps us selectively keep our mind focused on the information we want to hold in mind in working memory (e.g., Ed Awh; Adam Gazzaley).
The distinction between attention and working memory may be arbitrary. They appear to be similar in many ways, including neural basis.
Inhibition and Working Memory are tightly linked (each needs the other).

- Need to remember your goal (what’s relevant) in order to know what to inhibit
- Need to inhibit distraction to be able to concentrate on the relevant info held in mind
being able to easily & quickly switch perspectives or the focus of attention, flexibly adjusting to changed demands or priorities, being able to think outside the box.
For example, try to think of as many uses for a TABLE as you can.

What are all the things you might use a table for?
A table might be used to write on or to eat food on.

It might be turned on its side and used to keep a door closed or used as a shield against bullets or snowballs.

You could get under it to hide or to keep dry.

You could cut it up for firewood.
Note that shifting mental sets involves both:

- activating the new set (WM)
- de-activating the old one (inhibition)
Cognitive Flexibility appears years later than working memory or inhibition.
Dimensional Change Card Sort
(Zelazo, Frye, & Rapus, 1996)

Target Cards

- Shape: Star → Blue
- Color: Red

Holding two rules in mind, and inhibiting the tendency to continue sorting by the first dimension.
When sorting by COLOR, Correct Response is the Blue Star.

Card to be sorted:

Model Cards:
When sorting by SHAPE, Correct Response is the Red Truck.

Card to be sorted:

Model Cards:
3-year-olds sort the cards perfectly by either color or shape
but, very few 3-yr-olds can switch how they sort
2 VIDEOS
The child has clearly in mind what the new sorting criterion is and the appropriate rules for that dimension. BEFORE the stimulus appears the child is all set to perform correctly.
Then a stimulus appears that is relevant to both tasks, in incompatible ways. That creates a problem, triggering the mindset the child is trying to inhibit.
The core problem for 3-year-olds in switching appears to be:

**Attentional Inertia**

Once they have focused their attention on a dimension, their attention gets STUCK there. They need to disengage from, or inhibit, their previous way of thinking about the stimuli.
Helping Children Apply their Knowledge to their Behavior on a Dimension-Switching Task

Natasha Kirkham, Loren Cruess & Adele Diamond

*Developmental Science*

2003

vol 6, pages 449-467
It is not enough to know something or remember it; you must get that knowledge into your behavior.
Each dimension is an intrinsic part of the stimulus object.
What if both dimensions are not properties of the stimulus?
Roughly twice as many pass separated as pass integrated (3x at 3 years)
Roughly 6 months ahead on Separated vs. Integrated Dimensions

<table>
<thead>
<tr>
<th>Age in Months</th>
<th>Integrated Dimensions</th>
<th>Separated Dimensions</th>
</tr>
</thead>
<tbody>
<tr>
<td>29.3 – 34.4</td>
<td>10% 17%</td>
<td></td>
</tr>
<tr>
<td>mean = 32.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N = 19</td>
<td></td>
<td></td>
</tr>
<tr>
<td>35.8 – 40.4</td>
<td>18% 44%</td>
<td></td>
</tr>
<tr>
<td>mean = 37.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N = 24</td>
<td></td>
<td></td>
</tr>
<tr>
<td>41.2 – 45.7</td>
<td>41% 63%</td>
<td></td>
</tr>
<tr>
<td>mean = 43.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N = 14</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Children’s performance on the dimensional change card sort task: Separation aids ability to switch dimensions

Adele Diamond, Stephanie Carlson, & Danielle Beck

The role of selective attention in preschoolers’ rule use in a novel dimensional card sort. *Cognitive Development* vol 117, p 1-21

What causes 3-year olds' difficulty on the dimensional change card sorting task? *Infant & Child Development* vol 11, p. 93-105
Developmental Progression

Succeed at... at Age

Reversals (intra-dimensional shift) 2½
- extra-dimensional switches (1 dimen. to another) -

DCCS - Separated Dimensions 3½

DCCS (Standard) - Integ. Dimen. 4½

DCCS - Mixed Block.................. 7½
(switching dimensions randomly across trials)
Why are Executive Functions important?
Executive Function skills are more important for school readiness than are IQ or entry-level reading or math.

(e.g., Blair, 2002; 2003; Blair & Razza, 2007; Normandeau & Guay, 1998)
Executive Functions are also important for school success.

Working memory and inhibitory control each independently predict both math and reading competence throughout the school years.
Executive Functions are also critical for job success. Poor EFs lead to poor productivity and difficulty finding and keeping a job (Prince et al. 2007).
Executive Functions are also important for marital harmony. People with poor EFs are more difficult to get along with, less dependable, and more likely to act on impulse (Eakin et al. 2004).
Executive Functions are also important for making and keeping friends, for being accepted by other children.

Children with poor EFs often respond impulsively, have trouble resisting urges, & are forgetful; they don’t wait their turn, forget the rules that all agreed to, etc.
Poor EFs cause social problems such as disinhibited or criminal behavior.

The incidence of social problems reflecting poor EFs (crime, incarceration, and being unemployable) is increasing dramatically and the cost is staggering (Atkinson et al. 2005).
EFs are impaired in many mental health disorders
e.g., addictions, ADHD, OCD, depression, conduct disorder, & schizophrenia (Verdejo-García et al. 2006; Penadés et al. 2007; Diamond 2005; Lui and Tannock 2007; Taylor-Tavares et al. 2007; Barch 2005).

Such disorders are increasing at alarming rates (Moffitt et al. 2010; Robinson et al. 1999) & account for more lost years of life & productivity than any other illness including cancer (Prince et al. 2007).
Poor EFs can also lead to poor physical health including obesity, over-eating, poor food choices, substance abuse, & poor sustained adherence to doctors’ orders (Crescioni et al. 2011; McAuley 2011; Riggs et al. 2010).

In a large sample of >14,000, Miller et al. (2011) found that youths with poorer self-control were “exponentially more likely” to suffer from 9 of the 10 adverse health conditions they examined.
In short, EFs are core skills

- critical for cognitive, social, and psychological development,
In short, EFs are core skills

- critical for cognitive, social, and psychological development,
- success in school and in life,
In short, EFs are core skills

- critical for cognitive, social, and psychological development,
- success in school and in life, &
- for mental & physical health.
Many issues are not simply Education issues or Health issues. They are both.

EFs are important for academic achievement and for mental & physical health.
“Executive Functions” depend on Prefrontal Cortex and the other neural regions with which it is interconnected.
Central Sulcus
Frontal Cortex
Pons
Medulla oblongata
Unusual properties of the prefrontal dopamine system contribute to PFC’s vulnerability to environmental and genetic variations that have little effect elsewhere.
The best mechanism from clearing away released dopamine is by dopamine transporter (DAT) protein.

Dopamine transporter is abundant in the striatum but sparse in prefrontal cortex.
Striatum

= DA Transporter

= DA Receptor
Give an example of a gene that might directly affect the striatum.

Why?

What evidence supports that?
Polymorphisms of the dopamine transporter (DAT1) gene should be important for the striatum.
In ADHD that includes hyperactivity, there is a primary problem in which brain region?
In ADHD (combined type & primarily hyperactive) there is a primary problem in the striatum (PFC-striatal circuit)
Caudate Nucleus
Head of the Caudate

Putamen
Head of the Caudate
Putamen
Polymorphisms of the dopamine transporter (DAT1) gene should affect which brain region? and therefore should be linked to which types(s) of ADHD?
Polymorphisms of the dopamine transporter (DAT1) gene should be important for the striatum and for the forms of ADHD linked to the striatum (ADHD that includes hyperactivity -- combined type & primarily inattentive)
Levels of hyperactive-impulsive symptoms are correlated with the number of DAT1 high-risk alleles but levels of inattentive symptoms are not

(Waldman *et al.*, 1998)
DAT binding specifically in the striatum has been found to be related to motor hyperactivity but not to inattentive symptoms

(Jucaite et al., 2005)
In ADHD there is a primary problem in the striatum (PFC-striatal circuit).

I hypothesize that in ADD there is a primary problem in PFC (in the PFC-parietal network).
The dopamine receptor subtype, DRD4, is present in prefrontal cortex in humans, but not in the striatum. (Meador-Woodruff et al., 1996)
the 7-repeat polymorphism of the **DRD4** gene should be more strongly linked to which brain region?

and therefore be linked to which types(s) of ADHD?
Polymorphisms of the DRD4 gene should affect prefrontal cortex and therefore should be linked to ADD (inattentive type of ADHD)
DAT1 gene expression preferentially affects caudate volume, while DRD4 gene expression preferentially affects prefrontal gray matter volume (Durston et al., 2005)
A link between the DRD4 gene and ADD is consistent with the finding of Auerbach et al. (2001) Significant relation between individual differences in sustained attention & working memory and polymorphism of the DRD4 gene in normal infants (those with the 7-repeat-allele performing worse)
ADD is a different disorder from ADHD. They have....

- different cognitive & behavioral profiles,
- different patterns of comorbidities,
- different responses to medication, and
- different underlying neurobiologies.
ADHD children tend to be frenetic and hyperactive.

A significant proportion of ADD children are exactly the opposite - hypoactive, sluggish, & very slow to respond.
ADHD children tend to be insufficiently self-conscious.

ADD children tend to be overly self-conscious.
Both groups tend to have social problems, but for different reasons.

An ADHD child alienates other children by butting in, taking their things, failing to wait his or her turn, & acting without having first considered others’ feelings.

An ADD child is likely to have social problems because of being too passive or shy.
ADD children are not as easily distracted as easily bored.
Their problem is more in motivation (under-arousal) than in inhibitory control.

It is not so much that distraction derails them... as that they go looking for distraction because their interest in what they had started has dwindled.
Challenge or risk, something to literally get their adrenaline pumping, can be key to keeping their attention and to eliciting optimum performance.

(Note, the beneficial effects of Amphetamines, which release more DA & NE.)

ADD adults sometimes say they can focus better when driving if they speed than if they drive slowly.

ADD children often perform better on the continuous performance tasks when challenged by a fast presentation rate.
The dopamine transporter moves dopamine from the synapse back into the sending neuron.

Methylphenidate’s Mechanism of Action at Moderate to High Doses
The dopamine transporter moves dopamine from the synapse back into the sending neuron.

Methylphenidate blocks the dopamine transporter (1.e., blocks re-uptake), causing an increase in dopamine concentration at the synapse.

Methylphenidate’s Mechanism of Action at Moderate to High Doses
Most children with ADHD that includes hyperactivity respond positively to methylphenidate (Ritalin) in moderate to high doses.

Barkley et al., 1991; Barkley, 2001; Milich et al., 2001; Weiss et al., 2003
On the other hand, a significant percentage of children with ADD are not helped by methylphenidate and those who are helped often do best at low doses.

(Barkley et al., 1991; Barkley, 2001; Milich et al., 2001; Weiss et al., 2003)
Recent research suggests that low doses of MHP (dosages likely to be effective in treating ADD) preferentially increase dopamine release where in the brain?
Recent research suggests that low doses of MHP (dosages likely to be effective in treating ADD) preferentially increase dopamine release in the prefrontal cortex.

(Berridge et al., 2006)
A role for polymorphisms of the DAT1 gene in ADHD is consistent with the efficacy of high to moderate dose methylphenidate in treating ADHD, as methylphenidate acts directly on DAT function. (Dresel et al., 2000; Seeman & Madras, 1998; Shenker, 1992; Volkow et al., 1998)
ADD (ADHD without hyperactivity), a neurobiologically and behaviorally distinct disorder from ADHD (with hyperactivity)

Adele Diamond  (2005)

Development and Psychopathology, vol. 17, p. 807-825
Prefrontal Cortex

= DA Transporter

= DA Receptor
This makes prefrontal cortex more dependent on secondary mechanisms (such as the COMT [catechol-O-methyltransferase] enzyme) for clearing dopamine from extracellular space than are other brain regions, such as the striatum.
COMT Gene
catechol-O-methyltransferase
gene
codes for the COMT enzyme, which methylates released dopamine.
It’s located on chromosome 22.
A single base pair substitution

CGTG to CATG

translates into a substitution of

Methionine for Valine at codon 158
Why is COMT more important in prefrontal cortex than in other regions of the brain such as the striatum?
Prefrontal cortex is more likely to be affected by differences in the COMT gene or how fast the COMT enzyme clears dopamine than other brain regions because other brain regions have a lot of the best mechanism for clearing released dopamine (DAT protein) but poor PFC does not, so PFC needs to rely on alternative ways to clear DA, like COMT.
What effect does having methionine at codon-158 of the COMT gene have on level of dopamine in prefrontal cortex? Why?
Catechol-O-methyltransferase (COMT) Val158 Met

Low dopamine

SYNAPSE

High dopamine

High activity enzyme

COMT Val-Val

Low activity enzyme

COMT Met-Met

Zalsman et al.
Which variant of the COMT gene is associated with better PFC function and better executive functions?
The **Methionine** variant of the COMT gene is associated with better PFC function and better executive functions.
The Optimum Level of Dopamine in PFC is an Intermediate Level

Arnsten & Li, 2005
Differences in COMT Genotypic lead to Differences in PFC DA Levels

Optimal level of DA in PFC

too little  too much
Differences in COMT Genotypic lead to Differences in PFC DA Levels

Optimal level of DA in PFC

too little

Met-158

Val-158

too much
This effect is specific to PFC function:
There is no relation between the Met vs. Val allele of the COMT gene with IQ or other non-PFC functions.
Diamond et al. (2004) *American Journal of Psychiatry*
What’s the downside of Met variant of COMT?
Stress and Prefrontal Cortex

Even mild stress increases DA release in PFC but not elsewhere in the brain.

(Roth et al., 1988)
Genotypic Difference in PFC DA Levels leads to Genotypic Differences in Stress Reactivity

Effect of Mild Stress

too little  Met-158  Val-158  too much
Persons homozygous for the MET variant of the COMT gene (which results in more DA in PFC), while they tend to have better executive function, also tend to be more sensitive to stress, have higher anxiety, & higher pain stress responses.

Buckert et al. (2012): When stressed, young adults homozygous for COMT-Met\textsuperscript{158} showed worse EFs (performed worse on the 2-back test) than young adults homozygous for COMT-Val\textsuperscript{158} (the reverse of what is usually found). The presence of stress was confirmed by heartrate and salivary cortisol. When the task was too easy (1-back) or too difficult (3-back) there were no group differences.
Genotypic Difference in PFC DA Levels leads to Genotypic Differences in Stress Reactivity.
It has long been known that some of the brightest people also have the most fragile personalities and are highly reactive to stress.

Here is a possible mechanism for why the two might go together.

re: dandelion & orchid children
‘Dandelions’ are children who do okay wherever they are planted. They are often seen as models of resilience.

Perhaps children homozygous for COMT Val-158 are the dandelions; they will do okay even in a stressful environment, but might lack the exquisite fine-tuning of prefrontal cortex needed to achieve the brilliance of which a COMT Met-158 child might be capable.
Research shows that some of the children who look the worst when they are in an unsupportive, stressful environment are exactly those who blossom the most when in a good environment.

Perhaps some children homozygous for COMT Met-158 are among the orchids -- they might look like a disaster when in a stressful environment, yet might blossom brilliantly in the right environment.
The COMT Met-158 genotype, which confers risk on individuals when they are in adverse, stressful circumstances, holds out promise of extraordinary potential if only the right fit of circumstances can be found for the individual.

A child who is not doing well in one environment, or with a particular instructional style, might shine in another environment or with a different teaching approach.
GENDER DIFFERENCES

Why might the story (about which variant of the COMT gene is generally better for cognitive function) be different for women than for men?
Effect of Stress on Trace Eyeblink Conditioning in Male and Female Rats

Shors & Leuner, 2003
Even mild stress increases DA release in PFC but not elsewhere in the brain.

(Roth et al., 1988)
The Optimum Level of Dopamine in PFC is an Intermediate Level

Arnsten & Li, 2005
Hypothesis:

**Gender** Difference in Baseline Level of Dopamine in PFC
Hypothesis:

**Gender Difference in Baseline Level of Dopamine in PFC**

![Diagram showing gender difference in dopamine levels in PFC](image)
Hypothesis:
Gender Difference in Baseline Level of Dopamine in PFC

Female animals perform superbly at baseline (i.e., unstressed).
Gender Difference in Effect of Mild Stress on Level of Dopamine in Prefrontal Cortex

Females

Male animals perform better when slightly stressed.
WHY?

Why might Females have higher baseline levels of DA in PFC than Males?
Estrogen down-regulates human COMT transcription (Ho, 2006).

COMT activity is 30% lower in women than men.

Varies with estrus cycle in rats; inverse relation between COMT activity and estrogen levels.
Stress & PFC

Delayed Alternation

(Shansky et al., 2004)
Stress & PFC (Females only)

Delayed Alternation

(Shansky et al., 2004)
Hearts + Flowers:
(EF Task Sensitive to the Level of DA in PFC)

Better performance by VAL females when estradiol levels are high.

\[ t(186) = -2.432, \quad p < 0.017 \]

\[ t(179) = 3.229, \quad p < 0.001 \]

<table>
<thead>
<tr>
<th>Females</th>
<th>Val/Val</th>
<th>Met/Met</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIDLUTEAL</td>
<td>Val/Val, N=3</td>
<td>Met/Met, N=4</td>
</tr>
<tr>
<td>FOLLICULAR</td>
<td>Val/Val, N=3</td>
<td>Met/Met, N=4</td>
</tr>
</tbody>
</table>
Hearts + Flowers:
(EF Task Sensitive to the Level of DA in PFC)

Like males, better performance by MET females when estradiol levels are low.

![Graph showing mean RT (ms) for females in different conditions and genotypes.](image)

- **MIDLUTEAL**
  - Val/Val: N=3
  - Met/Met: N=4

- **FOLLICULAR**
  - Val/Val: N=3
  - Met/Met: N=4

Statistical tests:
- \( t(186) = -2.432, \ p < 0.017 \)
- \( t(179) = 3.229, \ p < 0.001 \)
Jeanette Evans

John Fossella, Elizabeth Hampson, Clemens Kirschbaum, C., & Adele Diamond

Jan. 15, 2009

Gender Differences in the Cognitive Functions Sensitive to the Level of Dopamine in Prefrontal Cortex.

Presented at inaugural conference of a series on "Executive Function & Dysfunction," University of Boulder, CO
What are possible implications of this gender difference?
If women have higher baseline levels of DA in PFC that would have implications for gender and menstrual-phase differences in the optimal dosage levels of medications that affect PFC DA levels.
But whether women have higher baseline levels of DA in PFC than males is ONLY A HYPOTHESIS.

There are no data on this yet.
HEARTS & FLOWERS

Congruent

Push Left

Push Right

Incongruent

Push Right

Push Left
HEARTS - CONGRUENT

Each time you see a HEART, press with the thumb or forefinger on the SAME side as the stimulus.

For example, if the heart appears on the left, press with your left hand.

Remember:

PRESS ON THE SAME SIDE AS THE HEART
FLOWERS - INCORRECT

Now you’ll see a flower. Press on the side OPPOSITE the flower.

For example, if a flower appears on the left, press with your right hand.

(Here, you’ll need to inhibit on every trial the natural tendency to respond on the same side as the stimulus)

Remember:

PRESS ON THE SIDE **OPPOSITE** THE FLOWER
HEARTS & FLOWERS-MIXED: Now you will sometimes see a heart and sometimes a flower.

On only half the trials will you have to inhibit the tendency to press on the same side as the stimulus, BUT you’ll have to switch between the same-side and opposite-side rules.

The rules stay the same:

For HEARTS, press on the SAME side.

For FLOWERS, press on the OPPOSITE side.

HEARTS - SAME SIDE

FLOWERS - OPPOSITE SIDE
It is *not* that children forget the rules.

Indeed, children often call out the correct higher-order rule on trials in the mixed condition (e.g., “same,” “opposite,” “opposite,” “same”) even as they are making errors.

The problem seems to be in quickly translating the rule into the correct response.
Hearts and Flowers Task: Accuracy

Percent Correct

Age in Years

4 5 6 6 7 8 9 10 11 13 26

Stimuli presented for 2500 ms
Stimuli presented for 750 ms

Adults

Congruent
Incongruent
Mixed

Davidson et al. (2006). Neuropsychologia, 44, 2037 - 2078
Dots Conditions: Accuracy

Percent Correct

Age in Years

Stimuli presented for 2500 ms
Stimuli presented for 750 ms

Davidson et al. (2006). Neuropsychologia, 44, 2037 - 2078
At every age studied, children were slower & less accurate on the Flower block than on the Heart block. That effect is completely absent in adults.
Even very young children have excellent memories. Inhibition is a far greater challenge for them than holding information in mind.
Abstract Figures - Center Presentation

Push Left

Push Right
Increasing demands on INHIBITION (the Flower block vs. the Heart block) are more difficult for young children (ages 4-9 years) than increasing demands on how much information they must hold in mind (2 to 6 items).
The opposite is true for us adults:
Increasing MEMORY demands is *far* more difficult for us than increasing demands on inhibition.
The costs associated with increasing MEMORY demands are greater for adults,

the costs associated with increasing INHIBITORY demands are greater for young children.
We adults may not appreciate how inordinately difficult inhibition is for young children because it is so much less taxing for us.
BREAK
hooray!
Nowhere is the importance of **social**, **emotional**, and **physical health** for cognitive health more evident than with PFC & EFs.

EFs are the **first to suffer**, and suffer disproportionately, if we are lonely, sad, sleep-deprived, or not physically fit.
To show the EFs they are capable of, to achieve the academic outcomes of which they are capable, students...

- need to feel joyful
- need to feel they are in a supportive community they can count on, and
- their bodies need to be fit and healthy.
Our brains work better when we are not in a stressed emotional state.

Amy Arnsten, 1998
The biology of being frazzled

This is particularly true for PFC & EFs.
Even mild stress increases DA release in PFC but not elsewhere in the brain

(Roth et al., 1988)
Stress impairs EFs and can cause anyone to look as if he or she has an EF impairment when that’s not the case.

(You may have noticed that when stressed you cannot think as clearly or exercise as good self-control.)
In college students, one month of stress in preparation for a major exam disrupts prefrontal cortex functional connectivity. Stress decreases coupling between left DL-PFC and right DL-PFC, and between DL-PFC and premotor cortex, the ACC, the insula, posterior parietal cortex (PPC), and the cerebellum.
Stress impairs their attention shifting (shifting between attending to color or motion).

Liston et al. (2009) *PNAS*
When we are sad we’re worse at filtering out irrelevant information (i.e., worse at selective attention).

Desseilles et al., 2009
von Hecker & Meiser, 2005

When we are happy we are better at selective attention.

Gable & Harmon-Jones, 2008
People show more creativity when they are happy

THE most heavily researched predictor of creativity in social psychology is mood.
The most robust finding is that a happy mood leads to greater creativity (Ashby et al. 1999). It enables people to work more flexibly (Murray et al. 1990) & to see potential relatedness among unusual & atypical members of categories (Isen et al. 1985, 1987).

Hirt et al. 2008: 214
Parents & teachers need to nurture themselves & find ways to help relieve their stress and students need ways to help relieve their stress & help them relax.

We need to reduce stresses in children’s lives. Children need to do things that give them JOY.
You’re not perfect.
You are going to make mistakes.
And, that’s OK.
You don’t need to be perfect.
Besides, no one ever is.
I can guarantee 100% that worrying about whether you are a great student will NOT improve your performance – it will only make it worse.
It’s okay to make mistakes; everyone makes mistakes. The only alternative is to stay with what you already know, to stop growing.
Anyone who has never made a mistake has never tried anything new.

- Albert Einstein
When we find out we were right, we’re not learning anything new.

It is only when we are surprised -- when we were wrong -- that we learn something we didn’t know before.

Venture into the unknown, take the risk of making a mistake or being wrong!

Be thrilled when your hypothesis is disconfirmed!
You've never failed until you've tried for the last time, and you've never lost until you quit.

-- Samuel Proctor Massie

Few people have attained the respect, admiration, and degree of excellence achieved by Samuel Massie, born in the segregated South. Born in Little Rock, Arkansas in 1919, Samuel Massie was the grandson of slaves. In 1966 he became the first African-American professor at the US Naval Academy. He was named 1 of the 6 best college chemistry professors in the US & one of the 75 premier chemists of the 20th century, along with Marie Curie, James Watson, and Francis Crick. In 1995 Dr. Massie’s portrait was hung in the National Academy of Science gallery and in 2002 the US Dept. of Energy chose to name its Chairs of Excellence in the environmental sciences in his honour.

It’s never over ‘til it’s over
PFC ↔ Stress
Putting Feelings Into Words Produces Therapeutic Effects on the Brain

When you put feelings into words, you increase activation in prefrontal cortex and that produces a reduced response in the amygdala.
Amygdala activation went up in ALL conditions when an angry or fearful face was shown, but ONLY in the one condition (a) where subjects had to assign a verbal label to the emotion, did amygdala activation GO DOWN.

Fig. 2. Parameter estimates of activity during five conditions (relative to activity in the shape-match control condition) in an amygdala region of interest (ROI). The ROI was identified by comparing activity in the observe condition and activity in the shape-match condition. The illustration on the left shows an axial slice indicating the extent of the ROI.
Inverse Relation between Activation in PFC and the Amygdala in the Lieberman et al. study

(When activation in PFC goes up, activation in the amygdala goes down.)
If you can get people to talk or write about their problems, their psychological and physical health improves.

--- James Pennebaker,
Opening Up: The Healing Power of Expressing Emotions
Translating an emotional experience into language, talking or writing about, alters the way it is represented and understood in our mind and our brain (gets prefrontal cortex more involved).
We are not just intellects,
we have emotions
we have social needs
& we have bodies.
Our brains work better when we are not feeling lonely or socially isolated.

*Loneliness: Human Nature and the Need for Social Connection*

2008

a book by John Cacioppo & William Patrick

This is particularly true for PFC & EFs.

- One group of subjects were told beforehand they’d have close relationships throughout their lives;
- another group was told the opposite;
- a third group was told unrelated bad news.

On simple memorization questions, the groups were comparable.

On sections involving logical reasoning (EF), subjects told they’d be lonely performed much worse.

Campbell et al. (2006) found that during math tests there was Prefrontal Cortex worked less efficiently among participants who felt isolated.
One of the best ways to support friends is to take the time to give them your undivided attention.
The most basic and powerful way to communicate that we care is to listen to them. Truly listen.

Give your time and your attention.

The quality of our listening, rather than the wisdom of our words, is often what has the most impact.
“Perhaps the most important thing we ever give each other is our attention. And especially if it's given from the heart…”

“Listening is the oldest and perhaps the most powerful tool of healing.”

-- Dr. Rachel Naomi Remen
“The greatest gift I can conceive of from anyone is to be seen by them, heard by them, to be understood.”

-- Virginia Satir
It's important is to be heard / understood – and to be liked anyway
When we interrupt to try to show we understand, we move the focus of attention to ourselves.

Because we care, we are tempted to want to do ‘more’ than ‘just’ listen. But often what a friend needs most is not for you to go into problem-solving mode, but just for you to listen - truly listen and care.
Fire

What makes a fire burn is space between the logs, a breathing space. Too much of a good thing, too many logs packed in too tight can douse the flames almost as surely as a pail of water would.

So building fires requires attention to the spaces in between, as much as to the wood.
When we are able to build open spaces in the same way we have learned to pile on the logs, then we can come to see how it is fuel, and absence of the fuel together, that make fire possible.

We only need to lay a log lightly from time to time.

A fire grows simply because the space is there, with openings in which the flame that knows just how it wants to burn can find its way.  

- Judy Brown
In Gottman’s studies, if a wife felt she was being heard the marriage was essentially divorce-proof.


“Differences must be grasped, even if no problems are solved. One of the reasons empathy works so well is because it does not require a solution. It requires only understanding.”

John Medina, *Brain Rules for Baby*
We are not just intellects,
we have emotions
we have social needs
& we have bodies
You need your sleep.
Lack of sleep will produce deficits in EF skills, and cause someone to look as if he or she has an EF impairment, like ADHD.
Our brains work better when our bodies are physically fit.

_Nature Reviews Neuroscience_ (January 2008)

“Be Smart, Exercise Your Heart: Exercise Effects on Brain and Cognition”
Charles Hillman, Kirk Erickson & Art Kramer

“There is little doubt that leading a sedentary life is bad for our cognitive health.”

This is _particularly_ true for PFC & EFs.
Evidence shows that physical activity (especially aerobic exercise) robustly improves cognition and brain function. In particular, the frontal lobe and the executive functions that depend on it show the largest benefit from improved fitness.

The positive effects of aerobic physical activity on cognition and brain function are evident at the molecular, cellular, systems, and behavioral level.
and there have been many more review papers since 2008 including:


The brain doesn’t recognize the same sharp division between cognitive and motor function that we impose in our thinking.

The SAME or substantially overlapping brain systems subserve BOTH cognitive and motor function.
For example, the pre-Supplementary Motor Area (SMA) is important for sequential tasks, whether they are sequential motor tasks or sequential numerical, verbal, or spatial cognitive tasks.

Hanakawa et al., 2002
Most cognitive tasks that activate dorsolateral prefrontal cortex also activate the cerebellum.

When dorsolateral prefrontal cortex activity increases so does activity in the contralateral cerebellum.

When dorsolateral prefrontal cortex activity decreases (e.g., when a task has been practiced and requires less concentration) so does cerebellar activation.

Activation in these two regions is strikingly correlated and closely coupled.
Motor development and cognitive development appear to be fundamentally intertwined.


Close interrelation of motor development and cognitive development and of the cerebellum and prefrontal cortex.

Child Development, 71, 44-56
When cognitive development is perturbed,
as in a neurodevelopmental disorder,
motor development is often adversely affected as well.
For example……

At least half of all children with ADHD have poor motor coordination & fit the diagnosis for developmental coordination disorder.

At least half of all children with developmental coordination disorder have ADHD.

Similarly for dyslexia, autism, and other disorders.
Science asked me to write a review of all interventions shown to improve EFs in young children

Interventions shown to Aid Executive Function Development in Children 4-12 Years Old

Science, vol. 333
accompanying online tables
Diverse activities including computer training, aerobics, martial arts, yoga, mindfulness, & school curricula have all been shown to improve children’s executive functions.
Many studies have found that aerobic exercise seems to improve prefrontal cortex function and EFs but all but 3 of those studies have either involved adults and/or examined effects of a single bout of aerobic exercise, where benefits may be transient.
Exercise alone appears not to be as effective in improving EFs in children as exercise-plus-character-development (traditional martial arts) or exercise-plus-mindfulness (yoga).
Lakes & Hoyt (2004) randomly assigned children in grades K thru 5 (roughly 5-11 years-old) by homeroom class to Tae-Kwon-Do martial arts (N = 105) or standard physical education (N = 102).
Children who had been assigned to Tae-Kwon-Do training showed greater gains than children in standard phys. ed. on all dimensions of EFs studied (e.g., cognitive [distractible — focused] and affective [quitting — persevering] - subtests of the Response to Challenge Scale). This generalized to multiple contexts and was found on multiple measures. They also improved more on mental math (which requires working memory).
Traditional martial arts emphasize self-control, discipline (inhibitory control), and character development.
In a study with adolescent juvenile delinquents (Trulson, 1986), one group was assigned to traditional Tae-Kwon-Do (emphasizing qualities such as respect, humility, responsibility, perseverance, honor as well as physical conditioning). Another group was assigned to modern martial arts (martial arts as a competitive sport).
Those in traditional Tae-Kwon-Do showed less aggression and anxiety and improved in social ability and self-esteem.

Those in modern martial arts showed more juvenile delinquency and aggressiveness, and decreased self-esteem and social ability.
Whether EF gains are seen depends on the way an activity is done.
Regardless of the program to improve EFs, a few principles hold:
1. Those with initially poorest EFs gain the most.

E.g., lower-income, lower WM span, or ADHD children generally show the most EF improvement from any program.
Children at-risk start school with worse EFs than more advantaged children and fall progressively farther behind each school year (O'Shaughnessy et al. 2003).
Thus early EF training is an excellent candidate for reducing social inequality (because it should improve the EFs of the most needy children most) -- thus heading off gaps in achievement and health between more- and less-advantaged children.
2. EF training appears to transfer, but the transfer is not wide. Computerized working memory training improves working memory but not inhibition or speed & probably not reasoning in children.
EF gains from training in traditional martial arts (Lakes & Hoyt, 2004) and school curricula (Raver et al., 2011; Riggs, Greenberg, Kusché, & Pentz, 2006) are wider, perhaps because the programs themselves address EFs more globally, so the transfer may not be wider but the programs address more EF components.
3. The largest differences between intervention groups and controls are consistently found on the most demanding EF tasks and task conditions.

Often differences are not found except on the hardest EF condition. It is in pushing the limits of children’s EF skills, that group differences emerge.
4. EFs need to be continually challenged to see improvements - not just used, but challenged.
Groups assigned to the same program, but without difficulty increasing, do not show EF gains.

Setting aside a time to work on EFs is less effective than working on EFs as part & parcel of everything you do.
The Importance of Repeated Practice

Whether EF gains are seen depends on the amount of time spent practicing, working on these skills, pushing oneself to improve.
Consistent with: what Ericsson reports is key for being truly excellent at anything — 10,000 hours of deliberate practice trying to master what is just beyond your current level of competence and comfort

(working in what Vygotsky would call the ‘zone of proximal development’)

Prefrontal cortex (what I specialize in) is over-rated.

To learn something new, we need prefrontal cortex.

But after something is no longer new, persons who perform best recruit prefrontal cortex least.
The DLPFC Slice for 8 Individuals
When something is new, those who recruit PFC most, usually perform best.

(Duncan & Owen 2000, Poldrack et al. 2005)

But when you are really good at it, you are NOT using PFC.

Older brain regions have had far longer to perfect their functioning; they can subserve task performance ever so much more efficiently than can prefrontal cortex (PFC).

A child may know intellectually (at the level of PFC) that he shouldn’t hit another, but in the heat of the moment if that knowledge has not become automatic (passed on from PFC to subcortical regions) the child hit another (though if asked, he knows he shouldn’t do that).
knowing what one should do

vs.

2nd nature (automatic)

(i.e., NOT dependent on PFC)
The only way something becomes automatic (becomes passed off from PFC) is through action, repeated action.

Nothing else will do.
“We are what we repeatedly do. Excellence, then, is not an act, but a habit.

We don’t act rightly because we have virtue or excellence, but we rather have these because we have acted rightly; these virtues are formed in a person by doing the actions; we are what we repeatedly do.”

Aristotle, *Ethica Nicomachea*, 4th century BC
The Importance of

...Action for Learning

...Learn through Doing
Hands-on Learning

We evolved to be able to learn to help us act, to help us do what we needed to do. If information is not relevant for action, we don’t pay attention in the same way (hence the difference in route memory for the driver, versus the passenger, of a car).

You learn something when you NEED it for something you want to DO.
(My son teaching me to program the VCR)

The same is true when we teach children in school. They need opportunities to concretely apply what they are taught.
We all know this, so why is so much of schooling still didactic instruction by the teacher, rather than active and hands on?
Almost any activity can be the way in, can be the means for disciplining the mind and enhancing resilience.

MANY activities not yet studied might well improve EFs.
It depends on the way an activity is done and the amount of time spent doing it, pushing oneself to do better. The most important element is probably that the child really want to do it, so s/he will spend a lot of time at it. It’s the discipline, the practice, that produces the benefits.
Might as well do something you can put their heart and soul into.
Circus Arts
could be caring for an animal....
SERVICE ACTIVITIES

activities where the children are working to help their community or people elsewhere

a goal larger than oneself --
helping children in Haiti, helping a local family whose home burned down, lobbying to get a new playground for the neighborhood
These are acts of caring and generosity, they require forethought, planning, and perseverance even in the face of setbacks, creativity and flexibility when unexpected obstacles or opportunities arise, and putting into use what they’ve learned in school. Each is a member of a group working toward an important shared goal.
Dancing Makes You Smarter

Vergheese et al. (2003) examined the relation between leisure-time cognitive activity or physical activity on the incidence of dementia. At the study’s outset all participants were at least 75 years and dementia-free. Five years later......
▪ Reading or doing crossword puzzles was associated with 35% reduced risk of dementia.

▪ Almost none of the physical activities offered protection against dementia – except dance.

▪ Dance conferred the greatest risk reduction of any activity studied, cognitive or physical – a whopping 76% reduced risk of dementia.
For 10's of 1,000's of years, across all cultures, storytelling, dance, art, & play have been part of the human condition. People in all cultures made music, sang, danced, did sports, and played games. There are good reasons why those activities have lasted so long and been found so ubiquitously.
Storytelling requires and invites a child’s rapt attention for extended periods (sustained, focused attention), and, working memory to hold in mind all that has happened thus far, different characters’ identities, and to relate that to the new info being revealed.
I predict that while Story-reading is wonderful, Storytelling should tax EFs more & so improve them more.
Music-making, singing, dancing, & playing sports address our physical, cognitive, emotional, & social needs.
These activities

...challenge our executive functions,

...make us happy & proud,

...address our social needs, and

...help our bodies develop
Because they challenge EFs directly, and indirectly support EFs by increasing joy, a sense of belonging, & physical exercise, I predict they should improve EFs.

(and we’re hoping to get funding to test my prediction for El Sistema Orchestra & for social, communal dance)
to recap this last portion:

‘Executive Functions’ are needed for the top-down control of behavior in the service of a goal. EFs are needed whenever going ‘on automatic’ would be insufficient or detrimental.
Executive Functions (reasoning, creative problem-solving, self-control, discipline, attentional control) are critically important for school success throughout all the school years.

Improving EFs improves Academic Outcomes
“Brain-based” does NOT mean immutable or unchangeable.

Experience and activity change the brain.

EFs depend on the brain -- but they can be improved by the proper activities.
• The importance of repeated practice.
  The only way something becomes automatic (becomes passed off from PFC) is through practice, repeated practice.
  Nothing else will do.

  “We are what we repeatedly do.”
  Aristotle

• Scaffolds can help someone practice a skill that he or she could not perform unaided.
We are not just intellects, we also have emotions, social needs & bodies.
The different parts of the human being are fundamentally interrelated.

Each part (cognitive, spiritual, social, emotional, & physical) probably develops best when no part is neglected.

Diamond, 2000
Our brains work better, and we have better EFs, when

- we’re not stressed or sad
- we’re not feeling lonely or isolated
- we’re physically fit
Translating an emotional experience into language, talking or writing about, alters the way it is represented and understood in our mind and our brain (gets prefrontal cortex more involved).
• What nourishes the human spirit may also be best for Executive Functions. Perhaps we can learn something from the traditional practices of people across many cultures & 1,000’s of years.

• The arts, play, and physical activity may be critical for achieving the outcomes we all want for our children.
The most effective way to improve EFs and academic achievement is probably not to focus narrowly on those alone, but to also address children’s emotional and social development (as do all curricular-based programs that improve EFs) and children’s physical development (as do aerobics, martial arts, & yoga).
While it may seem logical that if you want to improve academic outcomes you should concentrate on academic outcomes alone, not everything that seems logical is correct.
Thanks for your attention

The End