The brains behind
Challenge Based Learning
The Brains Behind Challenge Based Learning

One of the goals of my interactions with BEPiD is to use principles from the cognitive and behavioral neurosciences to examine the elements that most positively influence the innovative instincts and productive outputs of students in the program. As mentioned in the Service Proposal, we believe these efforts will result in students who are better learners, better innovative problem-solvers, more adept critical thinkers, and more thoughtful skeptics.

One important objective of this effort is to explore the pedagogical design factors that best aid and abet the preparation of the students who go through the program. To that extent, I have examined closely the design features of the Challenge Based Learning protocol, focusing on resources ranging from web-based materials to the teacher’s guide and two research evaluations of the program.

I have had two reactions:

First reaction. There are obvious similarities and references – some remarkable - between the design features of Challenge Based Learning and specific well-established principles in the cognitive neurosciences.

Second reaction. Those similarities and references were completely missing in these resource materials. The cognitive neurosciences, it seemed to me, were completely left out of the discussion.

The document you have in your hands is an attempt to fill in this gap. The goal is connect some of the science of learning to the design features of CBL that transform passive lecture based teacher driven models to student-based, exploratory models.

There are a total of 9 points of intersection. These pages describe these points, complete with references, and may be thought of as a textbook for an upcoming lecture series explaining some of the neurological basis behind CBL design. Accompanying this textbook is an outline for that lecture series.

These lectures – three in total - will be designed not only to explain the neuroscience behind CBL, but also to address skeptical educators about the merits (and challenges) of the program. More detailed notes and slides to accompany this textbook will follow next month.

I have been convinced for a long time that my field – the cognitive brain sciences - would never have much to say to educational programs that are well designed and well taught. I have been pleasantly surprised to recognize so many cognitive neuroscience principles anchored in the foundational features of the CBL program.

This forms the beginning of my analysis of the BEPiD project structure, ones naturally congruent with the research topics that will also be implemented as my analysis continues.

We begin, not with a CBL class in Campinas, but a physics class in Boston, Massachusetts. And with babies.

I hope you enjoy the journey.

John Medina
Order of topics

The points of intersection and lecture outline

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Introduction

What we can learn from Harvard’s Eric Mazur

Educators can be uncomfortable embracing exploratory models in teaching situations. They may even feel hesitant about the type outlined in Apple’s Challenge Based Learning materials.

There are numerous sources for such feelings, including unfamiliarity with the radical departure exploratory designs make over more traditional education models. Educators are most familiar with delivering information via stand-and-deliver lecture models.

That’s certainly what physics professor Eric Mazur of Harvard experienced. Switching from lecture-based methods to discovery-based methods was tough. He says “… evidence is mounting that readjusting the focus of education from information transfer to helping students assimilate material is paying off. My only regret is that I love to lecture.”

Escaping the 15th century

The problem is that lecture methodologies, designed from older 15th century European models, were not derived from anything empirical neurologically, such as unique insights into how the brain learns. That we still use these ancient models today, essentially unchanged since their first formation, is a source of astonishment to many of us in the brain science community.

Newer brain research is revealing how the brain actually learns things. What we are finding is that it is nothing like how 15th century lecture models work. The way the brain processes information is much more closely aligned with exploratory models than with traditional stand-and-deliver models, much more aligned with the core designs of CBL than with more standard lectures.

The organization of this document

The document you have in your hand seeks to show where this alignment exists. There are at least 9 points of intersection where the designs of CBL as described in Challenge Based Learning: A Classroom Guide align congruently with known information processing features of the human brain. The organization of this text will begin with a specific neuroscientific finding, including the supporting peer-reviewed references, then provide a quote from the CBL owner’s manual illustrating the intersection.

The underlying assumption is that education at its most fundamental level is all about brain development. It is the view of this neuroscientist that future teachers of the world need to become experts in how that development works – how the brain processes information. Though some of the practices in CBL may seem uncomfortable, they are hardly exotic, and they do not represent a passing fad. They are supported by reliable cognitive and neurological findings well described in the research literature, findings which appears to increase in both scope and volume with each passing year.

Quote from an award-winning Harvard physicist

“... evidence is mounting that readjusting the focus of education from information transfer to helping students assimilate material is paying off. My only regret is that I love to lecture.”

- Eric Mazur
**What we learn from babies**

Babies learn through a series of increasingly self-corrected ideas. They obtain this knowledge through a sophisticated form of hypothesis testing. They are natural scientists.

Hypothesis testing is defined the way Karl Popper and Francis Bacon have characterized it for decades (and centuries), divisible into the four familiar steps of the scientific method:

- **Step 1.** You make a sensory observation
- **Step 2.** You make a guess as to what is going on with your observation
- **Step 3.** You test your guess with an experiment
- **Step 4.** You evaluate the information obtained from the experiment, perhaps amending your observation as a result

**An example in peek-a-boo**

You can see active hypothesis testing at work in the game of "peek-a-boo" a game at which toddlers all over the world engage. It involves something we call "object permanence".

We will use the example of a coin hidden by a piece of paper.

Before about 18 months of age, babies all over the world believe if you hide the coin with the paper, the coin disappears. Vanishes forever. They lack the concept of object permanence, the insight that objects still exist even if they become hidden from view.

Around 18 months of age, babies all over the world start to challenge this faulty idea. For reasons that remain unclear, toddlers begin to understand objects will stay on the planet even if they are temporarily hidden. At first, however, they are not sure of this new insight. So they test it. They play "peek-a-boo", looking at an object, hiding it from view, removing the obstruction, revealing the object still exists, confirming the insight. They see the coin, place the paper over the coin, remove the paper, then react with delight as they realize the coin is still there.

One of the most delightful parts of human learning is revealed in the fact that toddlers all over the world often laugh when they see their insights are confirmed. We seem to start out life with a robust love affair with learning things on our own.
Why this is hypothesis-testing

If we dissect this peek-a-boo behavior to its component, the natural hypothesis testing features of the child’s brain are revealed.

**Observation.** Objects exist even if they are temporarily hidden from view.

**Hypothesis.** Baby hypothesizes if she hides the coin in front of her with a piece of paper, the coin will still exist if she removes the paper.

**Experiment.** She hides the coin with the paper, then removes the paper.

**Evaluation.** She squeals with delight as she recognizes the coin still exists.

Critical point: *Nobody teaches babies how to do this.* They hypothesis test naturally, and all over the world, leading most of us to think this is human learning in its native ground-state.

**Relationship with Challenge Based Learning**

Active hypothesis testing is so automatic in the human experience it is easy to miss it. And for years, the research world did miss it. Not any more. We now know active hypothesis testing is one of the most powerful learning features in an infant’s native cognitive tool kit. And it is sustainable. We remain active hypothesis testers throughout our life-times. Any learning environment that aids and abets such exploratory processes is naturally aligned with how the brain acquires information at its most fundamental levels.

Challenge Based Learning is designed to capture these hypothesis-testing features. By creating an “experimental style” aimed at solving real world problems, CBL forces a great deal of the learning responsibility onto the shoulders of the students. It then asks them to test their ideas. This is very much in line with the tendencies with which they’ve been working since they were toddlers.

Two quotes, taken from the *Challenge Based Learning: A Classroom Guide* support the alignment (from p. 4 and p. 13)

“*Challenge Based Learning begins with a big idea and cascades to the following: the essential question; the challenge; guiding questions, activities and resources; determining and articulating the solution; implementing the solution; evaluating the results; publishing the solution and sharing it with the world.*”

“*After identifying their solutions, the student will implement them, measure outcomes, reflect on what worked and what didn’t, and determine whether they made progress in addressing the challenge*”

**Relevant references**


Second point of intersection

Crystallized and fluid intelligence

Most of the cognitive gadgets of which hypothesis testing is composed remain mysterious, but researchers are closing in on a few of the components.

One experimentally helpful framework has been the model of Catell and Horn. They hypothesized years ago that human learning was divisible into two components: crystallized intelligence and fluid intelligence. I saw recognizable traces of their ideas as I read through the CBL text.

Here are the common textbook definitions of each type of intelligence.

Crystallized Intelligence. This is the ability to acquire and apply previously acquired knowledge to current problems.

Fluid Intelligence. This is the ability to deal with novel problem-situations, for which personal experience does not supply a solution.

Human learning is like a well-educated jazz player. The musician uses his crystallized database of music theory to both conceive and execute innovative solos during a jam session. This database store – and his access to it – is the hallmark of crystallized intelligence.

How creative an improvisation he comes up with does not depend upon crystallized intelligence, however, but on something else: his ability to use his knowledge in innovative ways. This is the hallmark of fluid intelligence.

Human learning is a balance between the ability to acquire and access a deep understanding of a fund of knowledge and the ability to improvise from that knowledge.

Relevance to the classroom

Research has shown there are ways to exercise both abilities, but the interaction between these types of intelligence is key to understanding how the brain learns in the classroom. Any environment that nurtures an interactive balance between these intelligences is something I always look for when evaluating the design of various curricula and accompanying teaching materials. It is easy get them out of balance.

Too much memorization. Any system that only emphasizes crystallized intelligence is in danger of creating students primarily used to memorizing things. It is vulnerable to producing only “robots”.

Too much improvisation. Any system that only emphasizes fluid intelligence at the expense of memorizing is in danger of creating students not having any previous knowledge upon which to make intelligent innovations. It is vulnerable to producing only “air guitarists”.

Some researchers believe these notions of Catell and Horn provide a powerful evolutionary context for the natural hypothesis testing tendencies of the human brain – the ones you can see in babies. I am one of them. They point to a notion known as Variability Selection Theory, first put forward by Richard Potts.
Hypothesis-testing meets the Serengeti

The idea behind Variability Selection Theory (VST) is that problem solving was greatly favored in the unstable environment of East Africa. This instability shaped how we learned and processed information over eons of time. VST can be described in three parts:

#1) Climactic instability. A wild series of global climate swings created an intense selective pressure for hominids living in East Africa. Human cognition was forced either to flexibly adapt to rapidly changing conditions or face extinction.

#2) Impact on survival – selection against. Those of our ancestors who could not intellectually adapt to such rapid change were doomed to extinction. Such pressure would select against inbred unlearned instincts beneficial only to narrowly defined ecological niches. It would also select against cognitive styles that could not learn readily from mistakes.

#2) Impact on survival – selection for. Intellectual traits favored under such unstable conditions would include the ability to solve problems rapidly in a wide variety of circumstances. What we adapted to was variation itself. The style in which this problem-solving manifested itself appears to have been a sophisticated form of hypothesis testing.

Here’s how I put it in my book Brain Rules:

> Our survival did not depend upon exposure to organized, pre-planned packets of information. Our survival depended upon chaotic, reactive information-gathering experiences. That’s why one of our best attributes is the ability to learn through a series of increasingly self-corrected ideas.

> “The red snake with the white stripe bit me yesterday, and I almost died,” is an observation we readily made. Then we went a step further: “I hypothesize that if I encounter the same snake, the same thing will happen!”

> It is a scientific learning style we have exploited literally for millions of years. It is not possible to outgrow it in the whisper-short seven to eight decades we spend on the planet.”

Relationship with Challenged Based Learning

What does this have to do with CBL? A large number of characteristics of human learning are predicted from the ideas of Catell, Horn and Potts.

One of the most obvious is that you have to have a fund of knowledge before you can improvise off of it. The goal is not learning per se, the goal is improvisation, for purposes of survival.

The best models out there might start with crystallized exercises, but would eventually “wean off” the students so that they became more used to self-generating ideas. It is no good if the teacher knows about the red snake. Survival is not achieved until the students internally know about it, too.

The interaction between these types of intelligences, along with a gradual movement from crystallized to fluid, are embedded within the curricular design of Challenge Based Learning.
Here are three quotes, from the pages of *Challenge Based Learning – A Classroom Guide*, that support these ideas:

…”you are actively guiding the process by making decisions, communicating information, teaching skills and answering questions about how the process works…”

Good for crystallizing the database. But there comes a time when it is important to cede control of the database, and turn learning over to the students, as this second quote suggests:

“In the middle stages, students take charge of planning and researching their own work, and you serve primarily as a mentor working alongside the students, helping them through the rough spots and keeping them on track.”

The third quote seals the deal, and the Serengeti is achieved:

“In the later stages, students are deeply engaged in their own work while you monitor the mastery of required knowledge and skills through appropriate assessments.”

Relevant references


**A matter of control**

There comes a time when it is important to cede control of the database, and turn learning over to the students.
Assessment and evaluation
How do exploratory models hold up when compared to more traditional models of learning? We actually know the answer.

Third point of intersection

Do student-centered, exploratory models actually work?

It is one thing to observe that a program’s design is congruent with the brain’s natural exploratory tendencies. It’s another thing to say that the design has been measured in the classroom and actually produces superior learning experiences over more traditional approaches.

Whereas double-blind randomized cross-over trials evaluating CBL in comparison to other learning programs have yet to be published, there are strong hints such research might be fruitful. To understand this optimism, I turn to the more molecular underpinnings in my career, some of which has been involved in evaluating psychoactive pharmaceuticals.

When assessing a medication, we ask the two canonical questions of the American Federal Drug Administration: a) is it safe? and b) is it effective?

Safety probably isn’t much of an issue for exploratory models. But efficacy is. How do exploratory models hold up when compared to more traditional models of learning?

Comparing exploratory models with more traditional approaches

We actually know the answer, some of the most rigorous work coming from University of Washington’s Lillian McDermott and Harvard’s previously mentioned Eric Mazur. When Mazur compared exploratory models to more traditional lecture formats, he found them superior in almost every way superiority can be measured. Across disciplines in numerous higher education facilities around the world, here is what he found:

“Data obtained in my class and in classes of colleagues worldwide, in a range of academic settings and a wide range of disciplines, show that learning gains nearly triple with an approach that focuses on the student and on interactive learning.”

Yes, triple. And he was able to show student-centered exploratory models even had bleed-through effects into other disciplines. Here’s a second quote from Mazur:

“Most important, students not only perform better on a variety of conceptual assessments, but also improve their traditional problem-solving skills.”

A matter of balance

Student-centered exploratory models aren’t a panacea of course. If students do not have some pre-existing fund of knowledge, they are likely to get lost if they are just “thrown in the pool” and expected to “swim”, without any prior instruction about the content to be explored or the methodology needed for the journey.
This “thrown in the pool” model has actually been measured. If students are assembled into groups and forced to grope their way through material with no direction, without any crystallizing framework formation provided by direct instruction, real failure occurs.

Here’s a quote from a *Science* magazine article, describing David Klahr’s work with students in a science and math class. The task was to design an experiment capable of answering a specific question.

“Half were told how to design valid experiments, the other half were left on their own. Not surprisingly, 77% of the instructed group, but only 23% of the discovery group – got most of the experiments right.”

That’s why the best designs possess both “crystallized” experiences (as a starting place) and fluid events (as an end goal) in any curricular design.

**Relationship with CBL**

The design of CBL has a healthy equilibrium of both elements. CBL is deliberately exploratory in nature, congruent with the best models of Mazur and McDermott. Yet it is balanced with the need for solid pre-existing informational framework, both standards-based content requirements and direct instruction about how to engage the discovery process.

Here are two quotes, from the pages of *Challenge Based Learning: A Classroom Guide*, which illustrates these clearly. The first quote describes the goal, which uses a pre-existing fund of knowledge as a starting point for exploration:

“For teachers, the task is to work with students to take multidisciplinary standards-based content, connect it to what is happening in the world today, and translate it into an experience in which students make a difference in their community.”

The authors go on to describe the necessity for teaching kids how to become natural explorers. They are essentially showing them how to reconnect with their own natural tendencies for learning – tendencies with which they were born.

“Accomplishing this goal necessitates giving students structure, support, checkpoints and the right tools to get their work done successfully, while allowing them enough freedom to be self-directed, creative, and inspired.

This balanced approach is very similar to the models of McDermott and Mazur. It is likely to reap the same experimental benefits these researchers have been demonstrating for years.

**Relevant references**


Fourth point of intersection

Why do student-centered, exploratory models work so well?

It is clear that properly designed discovery-based models work well for the transfer and manipulation of information in the classroom, better than many comparison models. Besides evolutionary arguments, are there additional hints from the research world that may shed light on the reasons why they are so successful?

There are clues in the brain sciences. These hints come from two well-established cognitive processing principles: the power of simulation and the power context-dependent and state-dependent learning.

The power of simulation

It is axiomatic that simulating real-world situations in classroom situations greatly enhances the transfer of knowledge from teacher to student, while simultaneously reducing errors and providing outlets for innovation and creativity out in the real world.

Simulations have been studied extensively. Empirical support for their value comes from many sources, ranging from medical and military training to business performance and pilot instruction. Two are mentioned here:

**Business simulation training.** Researchers have reviewed hundreds of papers investigating the efficacy of business simulations. Regardless of the subject, this analysis point to specific positive conclusions: Students that practice business skills in simulated settings become more adept at making complex decisions in the real world. They become less prone to error and enjoy an increase in competencies in a variety of measures outside those being tested by the simulations.

Here’s a quote from Dan Parisi, executive vice president of BTS, a global consultancy company.

> “The learning that takes place during a simulation helps participants increase competencies rather than simply build skills … analysis confirms that use of simulations correlates to market performance … when simulations are in use, the organization employing them is likely to be a high performer.”

**Medical training.** Researchers have also reviewed hundreds of papers regarding medical-training simulations, from computer-based training to robotic patients, and they too reach similar, specific positive conclusions.

Here’s a quote from David Cook, a physician in the Division of General Internal Medicine at the Mayo Clinic, writing a review article on the subject:

> “So what can we conclude in light of these findings? Available evidence supports the following recommendations: First, we should use simulation. The conceptual arguments for patient safety are compelling and these, together with the empirical evidence summarized above, support the use of simulation-based rehearsal in addition to (and often prior to) learning through working directly with patients.”
One of the empirical Dr. Cook cites involves medical professionals who had been taught to use a catheter the “traditional” way and compared competency with professionals who were taught using a simulation. Once they got out into actual clinical settings, professionals taught in the traditional way had 5.8 patient infections per 1000 catheter-days. In stark contrast, professionals taught using a simulator had 0.5 patient infections per 1000 catheter-days.

Context and state-dependent learning

Many of us believe simulations work because they exploit two specific well-described findings in the brain sciences. One involves processes termed context-dependent learning, the other called state-dependent learning.

Definitions for both can be summarized by a quip I often give in lecture to bioengineering graduate students, right before I explain these two processes.

“If you want the best shot at increasing your test scores, you should learn everything on that test in the same room in which you will also be taking it.”

I then go on to explain the following principle: we remember things better if we’re asked to retrieve them in the same physical sensorial context in which they were initially learned. This is context-dependent learning.

Such symmetry is also true for interior emotional states. If you’re sad when you learn the quadratic equation, you will remember it much better if you are made to be sad before asked you to recall it. The power is the symmetry of the psychological interiors between encoding and retrieval steps.

There’s a reason for this. Most of the cognitive processes that will determine whether something that is initially being perceived will also be remembered occur in the first few seconds of learning – where the brain is busy mapping the various contexts and states that surround the information being encoded.

When you are asked to retrieve something, the brain tries to recall those initial moments of learning, including the environmental components that originally surrounded the learner. That’s why it is helpful if those same environmental cues are made available at the moment of retrieval. The cues can either physical (context-dependent) or psychological (state-dependent).

Simulations, which in their most robust form mimic these cues exactly, aid this process. Simulations, in other words, are everything. That’s why we think they work.

Intersection with CBL

The left ventricle of CBL is the simulation of a real-world business experience. It is an attempt to recreate the types of scenarios students are likely to encounter as creative workforce professionals years after they’ve left the classroom. The very first sentence of Challenge Based Learning – A Classroom Guide summarizes this clearly:

“Challenge Based Learning mirrors the 21” century workplace. Students work in collaborative groups and use technology to tackle real-world issues in the context of their school, family, or local community.”

It then admonishes teachers to emphasize this real-world simulation philosophy:

“To stay true to its intent, make sure participants work in collaborative groups, authentically use technology commonly found in the workplace, tackle real-world problems using a multidisciplinary approach, implement the solutions with authentic audiences.”
If the students are going to be recruited to solve real world problems in the real world, what better way to get them started than to actively simulating the real world? With practice, their brains will be prepared to work in actual business settings years before they enter the workforce.

Relevant references:


Fifth point of intersection

Exploiting the benefits of top-down schema

Schemas are generally defined as a form of cognitive scaffolding, an organizing pattern of thought about some aspect of our world. The human brain creates schemas for physical objects, people, events, situations, just about everything we experience. Schemas can come in a “screenplay” format (called scripts), where we observe that some events seem to occur in a regular, sequential order, regardless of source. We learn to begin anticipating that sequence whenever familiar cues are encountered. Algorithms are a type of schema, cast in a systematized form. Schemas come in handy especially for repeatedly encountered information, though we can form them on the basis of a single exposure.

Schemas help learners organize otherwise disparate pieces of information into systematized frameworks. This renders the information more retrievable and, happily, more open to improvisation and innovation.

Though we create schemas to understand a great deal about our world, the brain processes some schemas more effectively than others. Schemas whose structures start with a “40,000 foot view” - a gist perspective - then deliberately move to specific details are processed more efficiently and are remembered better, too. Typical memory boosts of 45-50% are commonly observed in schemas ordered in a top-down fashion when compare to randomly ordered structures.

Relevance to CBL

If you want to establish and maintain a fund of information more effectively in a classroom setting, a curriculum should always start with big ideas, then commit to building a schema connecting these larger notions to smaller connecting minutiae. The connections should be obvious.

This hierarchical type of schema is something CBL clearly identifies as its main learning framework. CBL explicitly asks students to start with gist perspectives, then encourage them to move to local detail in an effort to solve some problem. This ordinal appeal to the large concept first can be seen in the opening pages of Challenge Based Learning - a Classroom Guide.

“Start by working with students to identify the Big Idea.” “A big idea is one that is important on a global scale...” “Challenge Based Learning begins with a big idea and cascades to the following: the essential question; the challenge; guiding question, activities and resources ...”

CBL then encourages students to move from the “40,000 foot view”, once identified, and take a more specific perspective, connecting the large ideas to a more particularized, localized solution.

“The Challenge turns the Essential Question into a call to action by charging participants with developing a local solution to a global problem.”

Any curriculum that identifies as its founding framework a gist-to-detail schema will create superior learning experiences over virtually any other model. The intersection between the design of CBL and the known cognitive benefits of top-down schema frameworks is clear and robust.
Any curriculum that identifies as its founding framework a gist-to-detail schema will create superior learning experiences over virtually any other model. The intersection between the design of CBL and the known cognitive benefits of top-down schema frameworks is clear and robust.

Relevant references


Sixth point of intersection

On the matter of meaning before detail

The following prioritization comes directly from the brain’s Darwinian heritage: the human brain processes the meaning of a given input before it processes the detail of that input.

What meaning means. It is axiomatic that the human brain is the world’s most sophisticated survival organ. The organ’s tendency is to organize all new information, including input from classrooms, into a subsistence hierarchy. Another word for “meaning” to the real world is “relevance” to the real world.

Example from saber-toothed cats. This hierarchy can be illustrated by examining the brain’s exquisite sensitivity to perceptions of threat. The brain does not care about the number of vertical lines in a saber toothed cat’s mouth before it cares about whether or not that mouth is going to clamp down on its owner’s thigh. It wants the meaning of that mouth before it wants the details of that mouth.

The brain is also hyper-sensitive to cues signaling reproductive opportunity – and pays a great deal of attention to inputs if it thinks they have been previously encountered (pattern matching).

Importance to the classroom

Given the brain’s natural prioritization features, any classroom-based information whose connection to the real world is readily apparent is going to be better processed – and better remembered – than information that is abstract and irrelevant.

If a teacher wants to establish and maintain a fund of information more effectively in a classroom setting, a curriculum should always start by describing the meaning of the input before describing the detail of that input. This prioritization is reminiscent of the schema discussion explained previously.

Relevance to CBL

CBL clearly describes relevance to the real world as a salient priority in its learning design, just as it does with schema. The priority is explicitly articulated throughout Challenge Based Learning - a Classroom Guide. Here are four examples:

“Next, work together to formulate the Essential Question, which serves as the link between their lives and the big idea.”

“It is important for the challenge to be real and meaningful to the students.”

“For teachers, the task is to work with students to take multidisciplinary standards-based content, connect it to what is happening in the world today, and translate it into an experience in which students make a difference in their community.”

“A good place to look for big ideas is the major news stories of the day.”
Any curriculum that prioritizes the meaning-before-detail aspects of a given input will create superior learning experiences over virtually any other model. The intersection between the desire of the human brain for real world relevance and the design of CBL is clear and robust.

Relevant references


Groups vs individuals: why teams are better

In the modern business environment, most creative problem solving is done by teams rather than by individuals.

This may be a good thing. On average, teams produce more creative solutions in a shorter period of time than individuals. This has been reliably measured using instruments such as the Wason Selection Task protocols. In one such experiment involving such tasks, 75% of teams solved a given problem in time, compared with only 14% of individuals.

Reasons teams are better

The research literature outlines two reasons why group interactivity results in more robust problem solving scores. One has to do with the ability to discuss a problem with peers, the other has to do with something researchers call c-factor.

Presence of discussion. Active peer engagement after a problem has been presented always increases the percentage of correct answers. Interestingly, the discussion also results in an increase in the confidence students have in their solutions. Responses to problems derived in isolation, where no peer discussion is allowed, always results in a decrease in correct solutions.

Here’s a quote from Smith et al, who examined this group vs individual phenomenon in an undergraduate molecular biology class:

“Our results indicate that peer discussion enhances understanding, even when none of the students in a discussion group originally knows the correct answers.”

It is possible that exposure to multiple points of view - such as would be available during discussion - allows more options to be considered, discarded or accepted. Regardless, even when the correct answer is not available, group discussion results in more efficient problem solving.

Presence of c-factor. Researchers have examined the fact that group problem-solving skills are unevenly distributed: some groups work quite well together and are remarkably productive. Others don’t work well at all and are inefficient problem-solvers.

Investigations into group dynamics during problem-solving discussions revealed the phenomenon of c-factor (collective factor). Groups who score high in c-factor tend to be very powerful problem-solvers. Those who score low tend to poor problem-solvers.

The components of c-factor have been isolated and are divisible into three categories, as shown on the next page.
Social sensitivity. Groups with high c-factor had high social sensitivity scores and were better at “reading each others’ emotions”

Conversational turn-taking. Groups with high c-factor interrupted each other less, no one person dominating the discussion.

Presence of women. The more women in the group, the higher the c-factor, the lower the presence of women, the lower the c-factor.

Relevance to CBL

If teachers want to create more efficient problem-solvers, their students should be allowed to maximize the time for peer-discussion and group interactivity. The groups should be selected for social competence and should be gender-balanced. Any curriculum that allows such social “ventilation” to be a regular structural feature will create better problem-solving teams than those that don’t.

CBL leans heavily on group interactivity to solve problems. The priority is explicitly articulated throughout Challenge Based Learning - a Classroom Guide. Here are several examples:

“Once the students understand the Challenge, organize them into teams so they can begin the search for a solution.”

“Challenge Based Learning is collaborative and hands on, asking students to work with other students, teachers, and experts in their communities and around the world…”

C-factor is not an active part of CBL design, though it would be easy to insert into the structure. There’s even a spot for it. Teachers are actively encouraged to talk about what makes teams work, as this quote explains:

“To help students become comfortable in their groups, provide guidelines for how to divide the work and give student tools to make meaningful contribution to the success of the team.”

Any system that includes peer-discussion as an active part of curricular design will create superior learning experiences over systems that provide only top-down lecture. The intersection between the benefits of peer-interactivity and the design of CBL is clear and robust.

Relevant references


Eighth point of intersection

On the matter of fostering creativity

Challenge Based Learning places a premium on designing innovative solutions to real world problems. While the goal is laudable, the formal neurosciences have a surprisingly hard time defining exactly what the CBL program means – or indeed any program means – when they mention “innovation” and “creativity”.

To this day there is no agreed to over-arching neuroscientific definition of creativity capable of satisfying all the scientists who are studying it. Most have surrendered to the notion that in order for an idea to be innovative it has to be both unique and useful on some practical level.

These ideas are summarized in this quote from an influential review article by Furnham and Bachtia.

“Despite its practical importance, the multidimensional nature of creativity makes it particularly difficult to define and measure. There are more than 60 definitions of creativity with no single authoritative and agreed upon definition, or operational measure. Nevertheless, the production of an idea or product that is both novel and useful is commonly accepted as a central characteristic of creativity.”

On the matter of cognitive disinhibition

Given these constraints, the cognitive device that probably comes closest to defining innovation in a neuroscientifically responsible manner is a process called cognitive disinhibition.

Noted Harvard psychologist Shelley Carson defines cognitive disinhibition as the “failure to disregard information that is irrelevant to some pre-established goal or thought process or activity.” It’s a conscious choice – a risky one - NOT to extract seemingly superfluous material from conscious awareness during a problem solving session. This is true even if the material seems so far-fetched it appears nearly irrelevant to the problem being considered.

There are two aspects to this notion worth noting.

On the matter of value judgments. The core idea is a willingness to entertain ideas that are not obviously related to the challenge at hand. That means keeping, at least for the time being, value judgments to a minimum. The net is cast as wide as possible into the ocean of ideas, with no “stuffiness” about what is initially allowed in.

On the matter of risk-taking. These processes involve an assumption of risk. There is no guarantee that what is being considered will either be unique or useful. The more options being considered, the greater the cognitive load, and the greater the risk of wasting time or energy. Yet options are not rejected out of hand, at least at first, simply because they run the risk of being wasteful.

Evolutionary considerations

There is adaptive significance to having these traits. In the unstable geophysical world of the Serengeti, unique problems related to survival faced our ancestors on a daily basis.
Those individuals who kept their ideas spread as broad as possible (in hopes of uncovering the best solutions per unit time) probably stood the best chance at solving – and surviving - whatever instability the environment gave them. The probability of passing along their genes increased markedly.

Those individuals without these important characteristics would not derive as many unique solutions per unit time. Their ability to solve problems and find unique solutions to the challenging instability of Eastern Africa would be hobbled when compared to their more creative colleagues. Compared to their more creative colleagues, the probability of passing along their genes was decreased.

Relevance to CBL

These notions have direct applicability to the classroom in general and CBL in particular.

Any curriculum that wants to increase the probability of finding unique solutions to practical problems will need to provide an free and open atmosphere - one open to new ideas without value judgment. Participants must be willing to assume the risks associated with such a judgment-free attitude regardless of the source.

CBL emphasizes this intellectual openness with force and enthusiasm. Challenge Based Learning - a Classroom Guide states specifically that all ideas are welcome without judgment, especially at the critical formative stage. Here are several examples:

“Make sure they (students) understand at this stage all ideas are welcome and every contribution gets recorded. Value judgments are not permitted, whether good or bad and everyone’s voice gets heard.”

“… ask students to brainstorm everything they know about the challenge and what they still need to discover to find a solution to their challenge.”

CBL encourages teachers to let this process play itself out in the minds of students, allowing for the fact that a) the teacher may not know the answers and that b) many “right ideas” will probably present themselves if the students are encouraged correctly.

“You do not need to personally know the solutions to the challenge ... The problems are big as well as real and the challenges will not be simple to solve. “Many “right” answers will exist, and the role of the teacher in Challenged Based Learning is to find the solutions with the students, not for them.”

If Shelley Carson is correct, any system that creates environments where open-ended idea creation is encouraged will create superior problem-solving experiences over systems that don’t. The intersection between the conditions necessary for cognitive disinhibition to flourish and the design of CBL is clear and robust.

Relevant references


On the matter of exercising Executive Function

Challenge Based Learning requires students to exercise a suite of cognitive processes called Executive Function, first characterized by Michael Posner. Executive Function embraces discrete behaviors that can be roughly divided into two large families: cognitive control and emotional regulation.

Though different laboratories include different subcategories within these families, most agree on the core salient features of Executive Function. Listed below are some of these, are taken from the model of Gioia and Kenworthy.

- **Initiation** - The ability to begin a task or activity and to independently generate ideas, responses, or problem-solving strategies.
- **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.
- **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.”
- **Emotional Regulation** - The ability to modulate emotional responses by bringing rational thought to bear on feelings.

The cognitive control components embrace the ability to consider a range of competing inputs, then select exclusively only certain items at the expense of others (kids with ADHD often fail at this). Another component of cognitive control is the ability to plan, to the point where one can predict the consequences of certain choices and behaviors. A final component is the ability to consistently evaluate and assess how the behavior or the plan is evolving in pursuit of some goal.

The emotional regulation components involve behaviors such as impulse control and the ability to introduce rational thoughts into emotionally charged circumstances.

Given the twin characteristics of cognitive control and emotional regulation, people with robust Executive Function skills tend to work well in team settings.

On the matter of education

Executive Function skills have proven to be a powerful predictor of success for people in both school settings and the workforce. Students who exhibit strong self-control behaviors do better on academic measures, both in grade point and in performance on standardized tests.
Here’s a quote from Roy Baumeister, an American researcher who has investigated this phenomenon extensively in both classroom settings and workplace environs:

“Self-control turned out to be the only trait that predicted a college student’s grade-point average better than chance. Self-control also proved to be a better predictor of college grades than the student’s IQ or SAT.”

Executive Function skills have also been shown to be a powerful predictor of success in the workplace. Adults with strong Executive Function skills set clear goals, are better at long-range planning, have less anxiety and depressive disorders and tend to function better in a crisis. They are usually popular managers, as this additional quote from Roy Baumeister attests:

“In workplaces, managers scoring high in self-control were rated more favorably by their subordinates as well as by their peers.”

It is obvious the high-levels of Executive Function are to be prized in both the classroom and the workforce.

One of the most interesting characteristics of Executive Function is that it can be improved in people – even those who score low in Executive Function assessments. For example, it is now abundantly clear that physical exercise (aerobics) can greatly improve executive function in ages ranging from elementary school students in classrooms to elderly populations in nursing homes.

Other behavioral exercises that force experimental subjects to exert executive control have also been shown to improve this suite of behaviors.

Relevance to CBL

Executive function is a powerful component of CBL design. Students that experience CBL are compelled to exercise their executive behaviors in many domains. This means CBL is a natural therapy – or mental “gym” – capable of improving a behavior known to aid both academic and workforce success. As shown below, CBL exercises the initiation, planning, organization of materials and self-monitoring subcategories (cognitive control components) of Executive Function.

Cognitive control

“... students will create an implementation and evaluation plan. The plan should include an in-depth description of the solution, how it was determined, where it will be implemented ... if time is available, the plan can include a beta testing process with multiple cycles of evaluation

“After considering the range of possible solutions, they select one through prototyping experimentation or other means.” “Although the exploration of the challenge will lend itself to multiple solutions, each group needs to select a single solution to develop and implement.”

“Using the research findings to identify and consider a range of supported solutions before selecting the one that will be implemented is a key element of Challenge Based Learning.”

By compelling students to work in teams, CBL also exercises the emotional regulation (impulse and emotional regulation) components of executive function. It even provides pieces of advice that could have come right from an executive function experimental therapy manual.

Impulse control

“Discourage the tendency to rush to a solution or to adopt the first solution they identify.”
**Emotional control**

“Establish a safe space where groups can air issues they are having, and encourage them to work out differences in a positive way. Have each group draw up a contract or outline that clearly states team member roles and perhaps even rules for group discussions that are developed by the student themselves.”

**On the matter of research**

One of the most exciting aspects of exploring Executive Function in CBL has to do with its research potential. It is easy to design focused experiments whose results might actually improve group performance in the BEPiD program. Aerobic exercise, as mentioned, is one of these.

Most of these experiments have been done in the laboratory – and none of them done in the BEPiD program? Do any of these translate to real-world improvements in BEPiD? Such questions represent fertile research ground.

But not just investigative opportunities. By its inherent design, CBL is built to improve executive function skills in the present. By compelling students to plan problem-solving strategies on their own, and having them work in teams, both wings of Executive Function get a work-out in this system.

Any system that creates environments where executive function skills are exercised and improved will create not only better students in the present, but better workers in the future.

**Relevant references**


Integrating science and practice

A life-long dream of mine has been to combine the science of learning with the practice of learning. CBL is one of those integrative threads that hold real promise towards realizing that dream. The intersections the program makes with these specific cognitive neuroscientific principles, from promoting hypothesis testing to exercising Executive Function, provide powerful real-world examples of this potential.

Education professionals would do well to pay attention to the anchoring biological and psychological ideas behind CBL, even if they feel uncomfortable with its methodologies, or feel initially resistant to implementing it in their own classrooms.

No system of education is perfect – and that includes Challenge Based Learning. But the fact that 9 components of CBL exist in such an easy relationship with the neurosciences makes learning this process not only an exciting teaching adventure, but a biological one too. The data seem to cluster around CBL like adoring fans at a rock concert.

That’s not a bad start if you’re interested in changing the way we teach. To me, this cheering is the single greatest reason why combining the science of learning with the practice of learning is so worth pursuing.

This concludes the mini-textbook portion of this document. What follows next are the outlines of three lectures which use these data to explain the merits of adding Challenge Based Learning to the educational experience of students.

John Medina
Based on the data from the previous pages

An outline of three lectures

Target audience of the lecture series

The target audience of these three lectures is professional educators whose job will be to introduce and implement Challenge Based Learning at a university level. It is assumed these educators have already been previously exposed to the mechanics of Challenge Based Learning (as explained in the work Challenge Based Learning – a Teacher’s Guide) and are facile with its basic design elements.

These notes could easily be re-configured for consumption by undergraduate populations.

Lecture #1 – intro to human learning

**Learning goal**
To introduce the natural history and cognitive characteristics of the human brain’s natural hypothesis testing and exploratory instincts.

**Part One**
Hypothesis testing, imitative behavior and what we can learn from babies.

**Part Two**
Variability Selection Theory and how a change in the weather gave birth to crystallized and fluid intelligence.

**Part Three**
An analysis of student centered exploratory models: do lessons from the Serengeti actually apply to the 21st century classroom? The answer is yes, depending upon how they are implemented.

Lecture #2 – a tale of three principles

**Learning goal**
To explain three basic cognitive neuroscience principles behind exploratory learning and to show how CBL uses these principles to aid and abet classroom learning.

**Part One**
The first principle: an explanation of the power of simulation and the notions of context-dependent and state-dependent learning on student performance.

**Part Two**
The second principle – a discussion of the concept of schema and an analysis of the cognitive efficiency of designing hierarchical schema in the classroom.

**Part Three**
The third principle – to describe how the brain processes meaning before it process detail and to explain how this principle works with the brains’ natural attentional filtering systems.
Lecture #3 – the power of teamwork

Learning goal
To explain the natural history of cooperative behavior and to show how creativity and Executive Function work in group settings. The lecture concludes with an extended review of how these principles intersect with the CBL program.

Part One
A discussion of the evolutionary advantages behind cooperative behavior and to show how teams in the 21st century, on average, produce more creative solutions in a shorter period of time than individuals.

Part Two
A discussion of how neuroscientists look at creativity (hint: we prefer the term cognitive disinhibition) and why exploratory models create the best conditions for fostering innovative solutions to real-world problems.

Part Three
An explanation of the importance of executive function, and the role it plays in both creativity and cooperative behavior in high-functioning teams.

Conclusion
A review of the intersection of these cognitive principles with CBL design.