Moving beyond rote memory towards trial-and-error learning

- an introduction to project-based learning

by André Croucamp

University students have created the acronym CPF to describe their learning experience. It stands for: Cram Pass & Forget. Think about your own school experience. How much of what you memorised for exams do you still remember? Could you remember it even two weeks after the exam? Cramming only alters memory temporarily.

Psychologists have been researching this phenomenon for more than 100 years. It began in the late 19th century, with German psychologist Hermann Ebbinghaus. His version of CPF is what we now call the "Ebbinghaus forgetting curve." Much more recently neuroscientists have identified what they call "intrinsic forgetting." The brain actively forgets what it experiences as unimportant and lacking in meaning. This should give us pause when we ask ourselves why learners forget what they studied for exams.

It is possible to cram and, with clever mnemonics and other memory tricks, get a distinction without understanding much, or being able to apply that knowledge to an unfamiliar (unrehearsed) challenge. How useful is that skill? We reward children for cramming, but how is this preparing them for a meaningful, sustainable and satisfying life? If we have to be intellectually honest with ourselves we have to admit that this kind of assessment, and the so-called learning that young people do for it, isn't teaching young people how to learn anything. It is an arduous, anxiety-producing ritual that adds little value.

Our education system often confuses what is in the textbook with what we think needs to be in a learner's head. Measuring memory makes up the bulk of our assessments and gives very specific signals to learners concerning what we value most about learning and what we consider the nature of useful knowledge to be. This approach has been reinforced by information processing metaphors and computer metaphors for the brain. But the way contemporary neuroscientists think about ***how the human brain learns*** is moving beyond computer metaphors. Thanks to their research we now know that your brain can't store and recall memories in the same way a computer does. This may sound counterintuitive, but the computer metaphor is inaccurate. This has huge implications for the way we teach.

This article is an attempt to convince you that we have made the mistake of confusing the rote memorisation of content with learning. This is perhaps the single biggest error in our education system.

Let's begin with a story that will help us reflect on the nature of human perception, memory and learning.

Seeing with sound – the story of Ben Underwood (aka Bat Boy)

In his book *Deviate* (2017) the neuroscientist Beau Lotto tells the story of Ben Underwood to illustrate important insights into the way we perceive, learn and remember.

> "Ben Underwood was born in 1992 in Sacramento, California, with retinoblastoma, a rare form of cancer that attacks the retina. The disease is most common in children and more often occurs just in one eye, but in Ben's case it was present in both. If not treated, it can spread quickly, so doctors had to remove first one of Ben's eyes, then the other. At just three years old he was left blind. His mother, Aquanetta Gordon, remembers vividly this heart-wrenching time, but says she knew he would be fine. She had been close to [a boy who was blind] growing up and seen how people over-helping him had disabled him further. "Ben was going to experience his childhood," she recalls, "and whatever it took for him to be that kid I wanted him to be that kid. I had complete confidence in him." She made him practice jumping up and down steps and do other challenging spatial tasks that sometimes upset him. But sure enough, by age four Ben began to adapt … by clicking.
>
> Using his tongue as a percussive instrument against the roof of his mouth. Ben clicked in his bedroom, in the living room, in the kitchen, even the bathroom. "He would go into the bathroom and just listen," Aqua says. "to the sink, the trashcan, the shower curtain, everything." She encouraged this, understanding that it was his new way of "seeing" his world. "'Make the sound baby,' I told him. 'No matter what you do, just make the sound.' It would've been so unfair for me to tell him what he couldn't see because he didn't have eyes." Ben himself was likely too young to understand what he was doing – which was simply the instinctive way his brain reacted to his newly sightless world. Through intuitive experimentation, he was learning to interpret the clicks that bounced back off of the world around him …
>
> Ben's clicking soon allowed him to sense his visual environment as a kind of acoustic landscape, and by the time he entered kindergarten he was able to navigate with confidence (and presumably a great deal of

courage). He could differentiate a parked car from a parked truck, and once he even recognized a particular neighbour by the sounds of her sandaled feet walking on the sidewalk five houses down the street.

Of course, Ben's odd technique has existed in nature for millions of years: *echolocation*, the same highly evolved sonic navigation system bats use. Ben's way of seeing differently allowed him to transcend the loss of his sight and live like a normal boy.

Remarkably, he rode his bike around his neighbourhood, played basketball and tetherball, and even beat his brother at video games by learning the significance of the different sounds. There were challenges, not just in the light injuries he occasionally sustained, but also in the minds of others. In contrast to his mother, his school administrators didn't want him to play on the monkey bars, and later on, his refusal to use a cane infuriated a school counsellor ...

Ben died at sixteen of his cancer, but he lived a life of enormous possibility and relative freedom to which we can aspire."

- Beau Lotto, *Deviate - the science of seeing differently* (2017)

Before reading further, reflect on the story by answering the following questions:

- How would you describe Ben's mother's attitude to his learning process after he became blind?
- In your own words, try to describe what you think was happening in Ben's brain when he was clicking.
- What attitudes and dispositions do you think were necessary for Ben to develop his strategy for engaging the world?
- How would your school respond to someone like Ben?
- What insights did you get from your answers to these questions? How could they inform your own teaching practice?

Perceiving reality through trial-and-error learning

Ben's brain was making a link between his sensory system and his motor system, so that he could respond to information that was reaching him from the world. Through trial and error performance he developed the technique of echolocation in order to navigate his environment.

This seems unusual, but it is exactly how we all learn. We all have to bump up against the constraints of our world through a process of trial and error. We have to risk some kind of performance – some kind of an experiment. Some of our experiments succeed in teasing reality into revealing itself. We push reality and reality pushes back. We call this feedback. Feedback can be seen as a flow of information, in the in-between spaces, that invites new responses, reinforces useful performances, or inhibits failed performance. Some of the positively reinforced performances become useful habits. Some feedback suggests that we have been unsuccessful at perceiving the world. We then edit our performance or abandon it entirely and try something else.

Most real learning happens when children are motivated to risk performance, through trial and error, get meaningful feedback they can reflect on, and then continue to experiment with changing their performance.

In a school environment we can ensure that feedback happens in a safe enough space for trial-and-error learning to take place. The real challenge facing us is to reframe failure so that learners do not fear it, but gain valuable insights through it. When there is no fear of failure learners will linger longer in the learning experience getting more out of it, reinforcing their natural curiosity and helping them to develop the confidence to work things out for themselves.

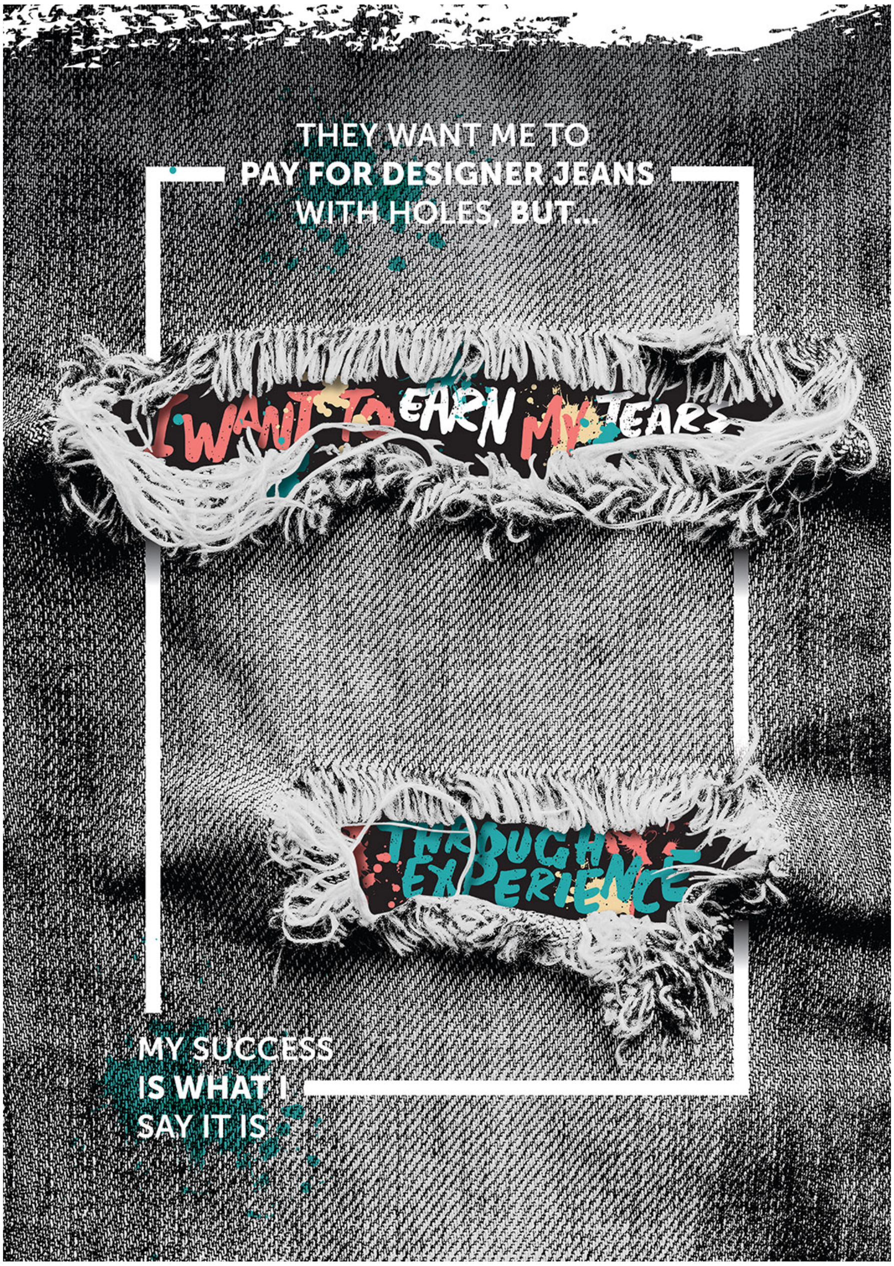
When neuroscientist, Lotto, reflects on the story of Ben Underwood he says,

> "Ben's story is a testament to human resilience and indeed innovation. His process of developing echolocation exemplifies how the brain innovates. Thus, from the perspective of neuroscience, his experience is not surprising (though it *is* exceptional). His life proves that we have the ability to physically change our brain … not in spite of its inherently interpretive, reality-removed nature but because of it. Ben's brain found an answer to that essential question … *What's next?* … because he cared to ... and his brain was evolvable toward this end. Instead of shutting down in the face of a profound subtraction from his senses, his perception found a new way to process his environment … at Ben's initiative.
> This is why trial and error action and reaction (feedback) … "namely, the response cycle" … is at the centre of perception."
> - Beau Lotto, *Deviate - the science of seeing differently* (2017)

In one of the workshops that MindBurst facilitates we play a game in which learners have to work together in teams and figure out what the hidden rules of the game are. There is minimal instruction. Learners have to do something, start somewhere, and risk experiment, so that they can bump up against the constraints of the game. Learners come up to us and say, "I am so confused." We reply, "Of course you are confused. You don't know what the rules of the game are … yet." Each time a new dynamic is discovered learners shriek in excitement. It looks like chaos, but in all their eyes there is a spark – the thrill of uncovering knowledge.

This kind of project-based learning encourages learners to work things out for themselves, through trial and error performance, adapting to feedback, not unlike what Ben was doing. It challenges the popular perception of learning as the passive process of receiving predesigned knowledge from a teacher or an expert. Of course, effective project-based learning is designed with clear outcomes. But instead of instructing learners, they are given the opportunity to explore within well-designed constraints and discover the knowledge and skills they experience as meaningful. The facilitator's job is to hold the space for that process of discovery.

When the playwright George Bernard Shaw was asked what advice he would give to parents about their children's education he said, "Don't get in their way."



This poster was developed in collaboration between Grade 10 learners at Sacred Heart College in 2016, MindBurst and the graphic artists at Paper Snap.

We have no direct access to, or accurate experience of, reality

We may think that Ben's experience was somehow reduced, and was not the real thing, as he was unable to see accurately and had to settle for an experience that was slightly removed from reality. But this is to assume that those of us who do have vision see reality accurately and that vision is more real than echolocation. This just isn't the case.

Beau Lotto's research focuses on visual perception, but has implications for all the ways in which you perceive the world. The first point that Lotto makes about perception is that you do not have direct access to, or accurate experience of, reality. Not only do your sense organs pick up very little of the available information, the limited amount of information that is received by your sense organs never reaches consciousness!

Your sense organs translate the information they receive into electrochemical signals. These electrochemical signals then get translated into what you experience as smell, taste, colour, sound, texture, temperature, pressure, etc.

Your conscious experience is never the stimulus itself. For example, colour is not a property of light. Colour is a property of the brain. Colour does not exist "out there." Colour is an internally generated neural performance (a pattern of nerves activating each other) that has been usefully associated with different wavelengths of light (electromagnetic radiation). When light energy strikes the rods and cones in your retina, chemical changes in these receptor cells trigger electro-chemical signals along your optic nerve. These signals travel to the brain's visual cortex where they are interpreted (associated with other neural performances) as colour. The experience of colour is something the brain has invented to distinguish between different wavelengths of light.

So how did a particular wavelength of electromagnetic radiation become associated with what we experience as "red"? The answer may be shocking at first: ***coincidence***.

Because you do not have a direct experience of reality your interpretations of all electrochemical signals are coincidences. The ones that have become habitual are the ones that have at least been partially successful in achieving some satisfaction or simply in not getting you killed. You inherited most of these happy coincidences (like seeing red) from your evolutionary ancestors whose experiments obviously succeeded and allowed them to survive.

Think about an organism surrounded by information. None of that information is perceived as meaningful in itself until it is linked to some personal experience. The organism has to create that meaning by risking a response to the information through some action, some performance. If the result of the performance is useful, the response is reinforced – the organism lives and reproduces other organisms with predispositions for similar performances. An ineffective performance could mean going hungry, being injured, being unable to reproduce, being rejected from its group, or death. Performances that succeed are reproduced and performances that fail die out.

Perception evolved as a tool for survival, to enable organisms to respond, to move (towards and away from), to perform actions and reactions. Initially, at least, since no organism could perceive anything in itself, the usefulness of a performance in response to stimuli (information that acts on the organism) was a coincidence.

The neuroscientist Lotto emphasises that:

> "To understand human perception, you must first understand that all information in and of itself is meaningless. The reason for this is simple: The information from the world that falls onto our different senses could literally mean anything. It is nothing more than energy or molecules. The photons entering our eyes, the vibrations through the air that enter our ears, the breaking of the bonds of molecules that creates friction across the skin, the chemicals that land on our tongues, and the compounds that enter our noses – all are just electro/chemical energy of one kind or another. These are the elements that emanate from our physical world – real reality, as it were. Yet we don't have direct access to those sources of energy, only to the waves of energy and gradients of chemicals that they produce … Information doesn't come with instructions. Instead, the "reality" that our perceptions see is the meaning of the meaningless information that your brain receives … the meaning your ecology gives it. It is critical to understand that the meaning of the thing is not the same as the thing itself. In other words, perception is similar to reading poetry: You are interpreting what it means, because it could mean anything. You make the meaning by interacting with the world (i.e. your ecology)."

Perhaps we should think of perception as the result of being creatively engaged with the world. It should be no surprise then that memory is also a creative act rather than straightforward storage and retrieval like a computer's memory.

If we move away from the idea of internal representations towards the idea of performances responding to feedback, we can start to think of brains and the world as mutually influencing each other. Think of the metaphor of dance. Regardless of how your brain may perceive the world, it is in a physical dance with the world. Brain and world respond to each other, dancing around each other, informing each other and inviting new responses from each other.

As the philosopher Alan Watts put it:

> "The boundary of the organism is also the boundary of its environment, and thus its movements can be ascribed to the environment as well … We gain better understanding by describing this boundary and its movements as belonging to both the organism and its environment".

Being creatively engaged

Computer-based metaphors for the mind are being questioned by an increasing number of researchers, like Anthony Chemero of the University of Cincinnati, the author of *Radical Embodied Cognitive Science* (2009), and Andy Clark of the University of Edinburgh, the author of *Surfing Uncertainty: Prediction, Action, and the Embodied Mind* (2015).

Chemero stresses that brains are nothing like information processing computers, and learn in ways that are very different. Chemero argues that perception and learning should be described in terms of the mutually influencing relationship between the actions of an environment on an agent and that agent's reactions to the environment, rather than in terms of computation and representation. Our perceptions are not accurate representations of what is "out there" and our brains are not passive receivers of sensory data, simply recording the world in a cumulative way (as many of our teaching practices would have us believe). No. Our brains, just like Ben's, are creatively engaged in the world. As far as perception goes, we are making it all up. Sometimes what we make up is useful, and sometimes it is disastrous. What is crucial is that performances are not fixed. They can change. Sometimes our performance and the feedback we receive in our dance with the world fill us with a wonderful sense of being meaningfully connected to something bigger than us.

Do not let our lack of direct access to reality make you think of the brain as "cut-off" from reality. Just because perception is a creative act doesn't mean that act is happening in isolation. It isn't. Brains are not enclosed spaces that download information from outside and organise it into stable internal representations of the world. We are not trapped inside the hard shell of a submarine navigating the ocean of reality reading data from the outside on a computer screen. No. We are performing in the world in relation to it. Clark explains that brains are completely integrated into the ecosystem, being influenced by it and influencing it, "complex nodes in a constant two-way flux in which the inner (neural) organization is open to constant reconfiguration by external (bodily and environmental) factors and forces, and vice versa."

This is a vision of mutually influencing performances in a complex interconnected ecosystem of relationships (that include the body, environmental elements, other organisms, social dynamics, language, substances, technology, etc.), providing feedback that is capable of changing the structure and the future performance of the brain.

We can talk about neural performances rather than neural structures, because the notion of structure reinforces stable internal representations, whereas performance is a more accurate description of what neurons do in relation to each other, the body and the world. These neural performances are patterns of electro-chemical activity between neurons, or nerve cells. These patterns are sometimes called neural pathways. A particular neural pathway with a particular sequence of activation strengths can generate a particular subjective experience, like your experience of redness. In fact there will be many different pathways that generate the experience of redness. They sill inevitably be slightly different from each other, although you may have no way of knowing in the moment of experiencing red.

Sitting behind a desk can make a child feel like they are expected to be an outside observer looking at reality as it is represented in textbooks, on blackboards or on monitors with some kind of abstract objectivity. A more natural state of learning is one that facilitates active participation and immersion in the world, risking experimental performances and learning from the way the world reacts and gives feedback to those performances. When a child engages the world fully it changes the way they perform in the world.

In an article on accommodating neuroatypical children (which usually includes children on the autism spectrum, children with attention deficit hyperactivity disorder and dyslexia – but depending on how you draw the lines, could include everyone) in learning experiences, Joi Ito says:

> "In addition to equipping kids for basic literacy and civic engagement, industrial age schools were primarily focused on preparing kids to work in factories or perform repetitive white-collar jobs. It may have made sense to try to convert kids into (smart) robotlike individuals who could solve problems on standardized tests alone with no smartphone or the internet and just a No. 2 pencil. Sifting out non-neurotypical types or trying to remediate them with drugs or institutionalization may have seemed important for our industrial competitiveness. Also, the tools for instruction were also limited by the technology of the times. In a world where real robots are taking over many of those tasks, perhaps we need to embrace neurodiversity and encourage collaborative learning through passion, play, and projects, in other words, to start teaching kids to learn in ways that machines can't. We can also use modern technology for connected learning that supports diverse interests and abilities and is integrated into our lives and communities of interest" (The Educational Tyranny of Neurotypicals in *Wired*, 9 June 2018: https://www.wired.com/story/tyranny-neurotypicals-unschooling-education/?mbid=social_twitter_onsiteshare).

Human brains are primed to learn in a real world context – a social context – rather than in abstraction. Learning is much more than decoding and encoding. This is especially true of very young learners.

(See: 'How babies learn – and why robots can't compete' by Alex Beard, *The Guardian*, 3 April 2018, https://www.theguardian.com/news/2018/apr/03/how-babies-learn-and-why-robots-cant-compete)

In their book, *Einstein Never Used Flash Cards: How Our Children Really Learn and Why They Need to Play More and Memorize Less* (2003) authors Kathy Hirsh-Pasek, Roberta Michnick Golinkoff and Diane E. Eyer show that repetition is important, but it is not what matters most. Context, relationship and experimental play are far more important. If repetition was effective on its own then digital devices that teach in abstraction (like many that are marketed to parents) would be an important tool in early childhood development. It turns out such mechanistic learning approaches are very limited. We learn through relationships where there is shared attention (which starts from about 9 months) and the co-creation of meaning. We know, for example, that children get more out of television when their parents watch alongside them.

The basics are not reading and math. The basics are a strong sense of belonging, engaging in meaningful relationships, and the freedom that these relationships give children to play and risk experimentation. And it is through paying attention to how children and young people play that we learn about what interests them – what they are trying to work out for themselves. We know how important stimulus and play is in early childhood development. If it is neglected the brains of those children do not develop optimally. Our children are over scheduled and over protected and have been deprived of valuable hours of self-supervision through play without overly-protective adults. Play enables them to experience the joy of discovery, opens up opportunities for them to discover each other in surprising ways, allows them to be vulnerable without being defensive, increases the chance of making unusual connections and harnesses the liberating power of humour. Even the conflict that arises in play is vital for children to experience and resolve on their own in order to develop the skills that will eventually enable them to participate in robust dialogue.

How can a more ecological model of learning change our teaching practice and school culture?

How can a more ecological model of learning integrate more diverse ways of knowing, doing and being into the learning experience of all children, meaningfully including a greater diversity of children in the process?

Predicting the future

Lotto's intellectual predecessor was Richard Gregory. In *Eye and Brain* (1966), Gregory described all perception as hypotheses. To recap briefly: Perception is not a product of the brain's ability to access information about the world accurately. It is a product of the brain's ability to fabricate functional hypotheses about what the world could be like, and then test it through experimentation. These hypotheses are not abstract representations but dynamic neural performances that respond to the sensory system (perception) and activate the motor system (physical performance).

Clark describes the "predictive brain" as "an action-orientated engagement machine" whose performances are "efficient embodied solutions that make the most of body and world." According to Clark, "Inner and outer here become locked in constant co-determining patterns of exchange" – in order to improve the process of making predictions about what will happen next. We could say that memory evolved, not to reproduce the past, but to predict the future.

> **Memory:** A general ability, or faculty, that enables us to interpret the perceptual world to help organize responses to changes that take place in the world.
> - Dictionary of Philosophy of Mind
> (https://sites.google.com/site/minddict/memory)

In reality the future is not always like the past, so simply reproducing an accurate copy of past experience (what we incorrectly tend to think of as memory) is not enough. This is especially true for humans that have to deal with complex experiences and social contexts that are inconsistent and are full of subtleties and nuances. A human needs to be able to associate activation habits in ways that are highly adaptive. The brain needs to be able to make associations between active neural performances happening in the now with numerous neural activation habits that were performed in response to past experiences. This is not automatic or a neat one-to-one association between past and present. It is a kind of trial and error process in which lots of different associations are made, many of which are of no use at all, and only some of which could contribute to a useful response. Our prediction error or prediction success changes the way those neurons could potentially perform in the future.

Even what seems to be a coherent memory of the past is not a single copy but a cut-and-paste of different components from different parts of the brain. Since the components that you associate in the process of remembering are not coherent internal representations but different performances there is no way of knowing whether the resulting web of associations is consistent with anything you have experienced before – unless you can compare it to a recording in a book, or on a computer, or in a film, or some other form of external storage.

It is important to note that while we know a lot about how neurons work, we are still not entirely sure how they give rise to the subjective experience of what it is like to be you.

Rethinking how memory works

So how does human memory work?

Rather than being stored accurately, memories are performed from scratch each time, with a fair amount of inconsistency, through a decentralised, distributed process of making associations. You are not just replaying a scene you are reconstructing it from many different components all over the brain.

In order to "retrieve a memory" it is necessary to experience an input or a cue that triggers a pattern of associations between nerve cells or neurons. This could be a molecule hitting the olfactory nerve triggering the smell of your favourite home-cooked meal, which in turn may trigger any number and combination of neural firing habits or components associated with that smell. One chain of associations may lead to a recreation of your mother's face. That in turn might create the associated neural firing habits that make you feel warm and loved.

When you try to remember something, your search is not for the correct label but for associated (matching) performances. We remember things through association, not through labels or addresses as most computers do.

> "The difference between remembering through labelling and remembering through association is nicely illustrated by comparing the recovery of one's hat from a cloak room and from a lost-property office; the former involves submission of a ticket, while the latter requires a description"
> - R. Cotterill, *Enchanted Looms – Conscious Networks in Brains and Computers* (1998)

You may even "recall" related things before "recalling" the desired association. The "recollection" of the wrong items occurs because they bear a resemblance to the association we need. Our final "recollection" is always partial with some amount of fabrication, which is subjectively indistinguishable from actual past experience.

When these neurons are not firing at a particular strength and in a particular pattern, the associations are not there! When you are not thinking of your mother's face it is not stored anywhere. It only appears in the re-enactment. Furthermore, this re-enactment is not completely accurate. It changes over time, and is different in different contexts, in ways you cannot even be aware of.

> "A memory is only made when it is called upon. In its quiescent state it is not detectable. Therefore we cannot separate the act of retrieving and the memory itself. Indeed, bits and pieces of a single memory are stored in different networks of neurons all around the brain. We bring the pieces together when it is time to recall that memory"
> - John J. Ratey, *A User's Guide to the Brain* (2001)

The brain does not have to store an incredulously high number of complete memories. Instead, it reconstructs them from a manageable number of reusable components. A complete, discrete and coherent memory is not stored in a particular part of the brain. There are in fact many different robust ways of recreating versions of your mother's face, depending on the context in which you are remembering them. From the point of view of subjective experience, the version in your current experience may seem indistinguishable from others you remembered previously. Your brain will even fill gaps in your memory with good guesses. Think of a movie you enjoyed many years ago. Over the years as you have tried to remember it you have distorted it and added to it each time you reconstructed it. When you see it again many years later it is not exactly what you remembered. You cannot tell the difference between what really happened and what memory has been fabricated during the years of nostalgic reconstruction. A lot of what we remember we are just making up.

> “Remembering is not the re-excitation of innumerable fixed, lifeless and fragmentary traces. It is an imaginative reconstruction, or construction, built out of the relation of our attitude towards a whole active mass of organized past reactions or experience. . . . It is thus hardly ever really exact.”
> Frederic Bartlett (researched memory in Cambridge in the 1920s and 1930s)

It is actually advantageous that human memories are not stored accurately or completely as in a computer. While an inaccurate memory may seem like a disadvantage, the advantage lies in the potential for malleability, creative associations, useful reinterpretations and the ability to transfer knowledge from familiar contexts to unfamiliar ones. Our imperfect memories are the source of our creativity.

Memory must be stable enough for the human organism to be able to learn and build on past experiences, but it also has to be flexible enough to adapt to a changing environment.

> “The living being is stable. It must be in order not to be destroyed, dissolved or disintegrated by the colossal forces, often adverse, which surround it. By an apparent contradiction it maintains stability only if it is excitable and capable of modifying itself according to external stimuli and adjusting its response to the stimulation. In a sense it is stable because it is modifiable – the slight instability is the necessary condition for the true stability of the organism”
> - Charles Richet, *Dictionnaire de Physiologie* (1900)

This is the strange and wonderful dance of:

order and change,

habit and novelty,

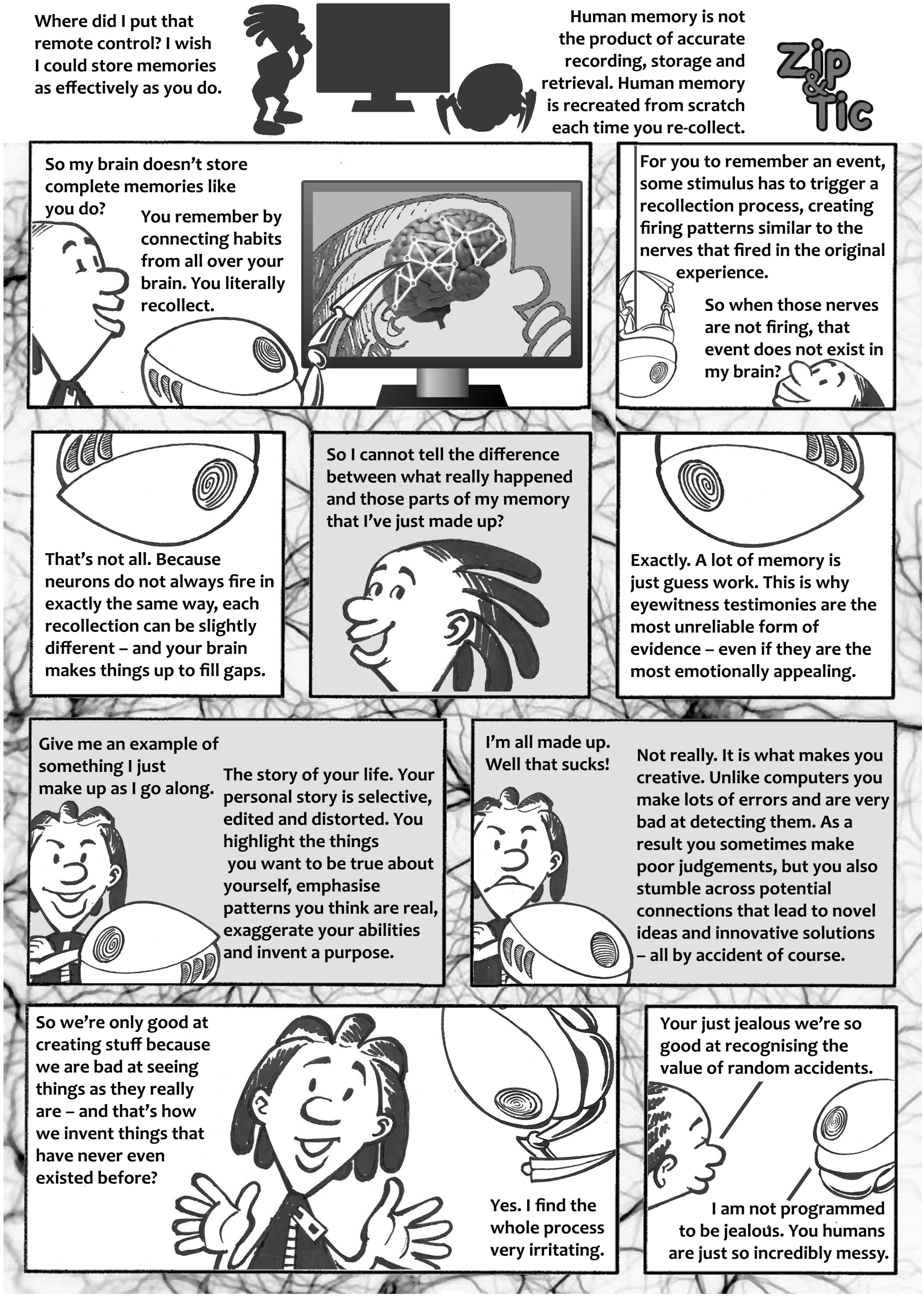
predictability and flexibility,

convention and innovation,

orthodoxy and heresy,

“safety and surprise”
(as a Doors song puts it)

If a system changes too much it can lose coherence and come undone. If it is too stable a system can become rigid and unable to adapt to radical environmental changes.

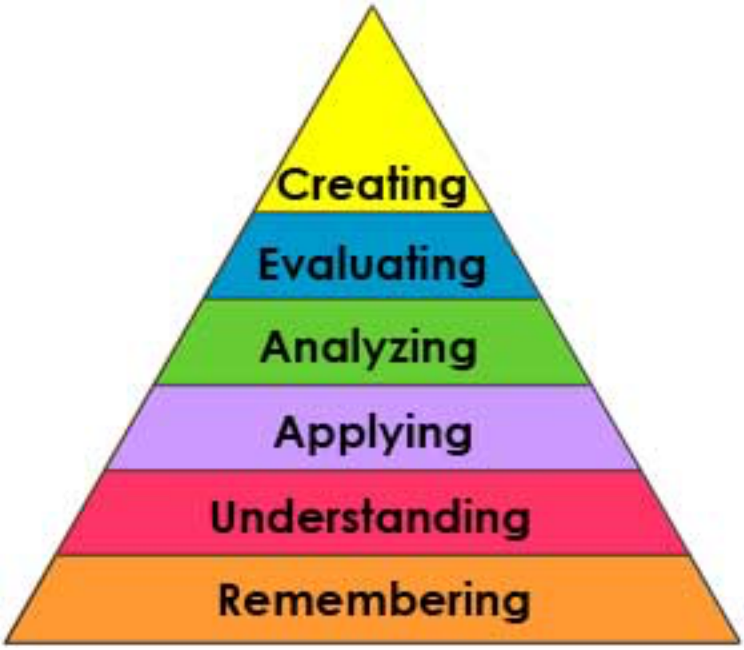


This comic forms part of the self-study modules on critical thinking skills MindBurst Workshop developed for Sacred Heart College

A misappropriation of Bloom's taxonomy

We tend to give memorising priority by allocating most of the marks we give learners towards it. I have heard this being defended by the idea that it is a measurable outcome that the majority of learners are capable of.

While this is not even true, it implies, in a misappropriation of Bloom's taxonomy (below), that fewer learners are capable of understanding, even fewer of application, and only a small percentage of analysing, evaluating and creating.



The version of Bloom's taxonomy as it was revised by Lorin W Anderson and David R Krathwohl in 2001.

Instead of expecting learners to develop all these skills, we have convinced ourselves that only smaller and smaller percentages of learners are capable of ascending the perceived hierarchy of Bloom's taxonomy. This is a mistake. Learners who are skilled in analytical thinking or creative thinking are not necessarily skilled in rote memory. The system is punishing the very skills needed to survive in the 21st century.

It needs to be emphasised that Bloom's taxonomy, with rote memory at its base, was influenced by information processing metaphors. We need to re-evaluate Bloom in the light of new brain research. If we had to apply the contemporary understanding of memory to Bloom's taxonomy, all the thinking skills would be forms of associative memory.

Moving beyond memorising content towards transferable skills

The idea that we can upload information into learners' heads in any useful way, and then assess those learners on the basis of their ability to reproduce the information needs to be challenged. Of course, accurate replications of abstract information or procedures that have been rehearsed through repetition in a classroom are easy to assess. But we need to question whether we should base what we teach on how easy it is to assess or on what learners need to thrive in the 21st century.

Leading educators and educational institutions all over the world are saying that content should no longer be the priority. Content will keep changing, and is changing more rapidly than ever before. Many textbooks are out of date before they are even printed. Learners can also access content online in ways that were never available to their parents and teachers.

The challenge facing us is to go beyond prescribed content and teach learners the transferable skills the need to engage any content in any context, so that they can become active agents of their own knowledge production. This requires a focus on "how to think" rather than "what to think".

A good example of this difference can be seen when science teaching and science textbooks succeed in teaching the "what" but fail to teach the "how" of critical thinking. The research of Richard Walker, Steven J. Hoekstra, and Rodnet J. Vogl ('Science Education is No Guarantee of Skepticism' on Skeptic.com, http://www.skeptic.com/eskeptic/12-03-07/#feature) shows that we cannot assume critical thinking is being learnt during science classes. Having memorised information about science is not enough to insulate a person against irrational beliefs. The researchers say:

> "We suggest that this inability stems in part from the way that science is traditionally presented to students: Students are taught *what* to think but not *how* to think."

Their analysis of science textbooks shows that:

> "Little or no discussion is given to the importance of evidence or how scientific methods can be used to weigh evidence. Instead, the primary emphasis of many texts is to enumerate as many scientific findings as possible. Since it is reasonable to suspect that many instructors follow the basic format of the text that has been selected for class, it is likely that class lectures spend more time on specific research findings than on the more abstract topics of empiricism and scepticism. Hence, it is possible for a student to accumulate a fairly sizable science knowledge base without learning how to properly distinguish between reputable science and pseudoscience."

One way to shift the focus from "what to think" to "how to think" is project-based learning. For example, in a lesson designed by MindBurst learners work in Crime

Scene Investigation teams to analyse the garbage from a house belonging to a suspect. This lesson was developed to create an experience of grappling with evidence. It is designed so that no single piece of evidence tells a story. The different bits of evidence have to be connected to each other before telling a probable story. Learners have to:

- follow instructions;
- create an effective group strategy for collaborating on a complex task;
- identify relevant information and separate it from irrelevant information;
- arrange the relevant information (evidence), into some kind of narrative;
- 'zoom out' and see the big picture, and 'zoom in' and see the detail;
- find connections between diverse sources of information in a short time;
- create a working hypothesis of what the information might point to.

A project-based learning approach:

- o encourages learners to work things out for themselves, through trial and error performance, adapting to feedback;

- o engages learners in immersive, sensorial, physical, emotional and intellectual experiences that are relevant to them, rather than abstracted knowledge that has no meaningful context;

- o challenges the popular perception of learning as the passive process of receiving predesigned knowledge from a teacher or an expert;

- o focuses on open-ended questions and unresolved challenges for which there aren't necessarily any predictable or correct answers;

- o reinforces intrinsic motivation, going beyond the extrinsic motivation of marks, rankings of learners and awards;

- o encourages a growth mindset in which learners experience themselves as able to adapt to change with as little anxiety as possible;

- o models what it is like to collaborate on problem solving in the world of work and diverse forms of activism;

- o shows the deep knowledge structures that different subjects share and how they are interconnected in real world systems.

Identifying the transferable skills a project is going to focus on is sometimes a challenge for us when we have been used to focusing on content. Examples of transferable skill sets are the ability to:

- o research, by comparing diverse sources, finding the similarities and differences that generate valuable insight (conclusions), and referencing accurately;

- risk experimentation by breaking convention and going beyond the comfort of predictable thinking habits and practices;
- innovate, by combining different variables (ideas, media, materials, technologies, performances, etc.) in unique and unusual ways;
- read an image (visual literacy), identifying the devices that have been used to manipulate the viewer, as well as the intent of the producer;
- transfer knowledge (techniques, perspectives, principles, insights) from one familiar (or rehearsed) context to an unfamiliar one;
- think systemically, zooming in to see the detail of parts, and zooming out to see the big picture in which the parts interact to form the whole;
- plan strategically, agreeing on a collective goal, imagining a production process, creating schedules and roles, as well as managing resources and time;
- collaborate with diverse dispositions, being assertive while listening to other points of view, staying committed to creating the best solution possible;
- persevere, without giving up when the solution is not immediately obvious, being willing to learn from mistakes, deal with feedback and start again.

This is a less radical shift than you may think. Effective teaching practice has always done this. You probably do it more than you realise.

In the pages that follow we'll expand on our understanding of trial-and-error learning by exploring the concepts of intrinsic motivation, a growth mindset, collaboration and resilience.

Extrinsic and intrinsic motivation

In schools, the extrinsic motivation of marks, ranking of learners and awards (according to narrow criteria for success, mostly based on rote memory) causes learners to focus more narrowly, and with more anxiety, on short-term goals. This narrow focus doesn't enhance their understanding of the broader context in which they are learning. The accompanying anxiety interferes with their creativity and their ability to make unusual connections between things, connections that might lead to an original insight into deeper patterns of knowledge or an unexpected innovation. In his book, *Drive: The Surprising Truth About What Motivates Us* (2009), Daniel H. Pink showed that in tasks requiring higher level thinking skills (i.e. tasks that are not routine, algorithmic, or step-by-step) extrinsic rewards actually decrease performance. The extrinsic rewards of high marks and recognition reinforce routine, algorithmic, step-by-step tasks – and not understanding. Learners are encouraged to take short cuts that meet the stated objectives as efficiently as possible, rather than make the most of the learning experience.

Intrinsic motivation, on the other hand, relies on what excites the learner. The reward is in the satisfaction the learner gains from the task – stimulating the learner's curiosity, independent agency, need for purpose (in the service of something larger than themselves), desire to get better at something important to them, and deep sense of participation.

Extrinsic carrot-and-stick motivation that gets people narrowly focused on external rewards (like money or marks) can also limit them to short-term horizons. Intrinsic motivation is far more likely to enable learners to embrace a long-term view of things. If a learner's time horizon does not stretch very far, an experience of failure can define them in that time frame, because it feels so immediate. If they can project further into the future, because they have a vision (even if that vision changes – having it is more important than keeping it the same), then failure informs them rather than defines them. In the context of a long-term vision, failure is a piece of information that, if they are willing to learn from it, can change the quality of their journey. Resilience has a lot to do with being able to learn from failure and having a long view of things in which you are willing to risk experiments.

Educational psychologists Adele and Allen Gottfried have explored the role of motivation in academic performance and success in life. For forty years they followed a group of 130 babies that were born in a hospital in Fullerton, California. The data they collected has become known as the Fullerton Longitudinal Study. According to the Gottfrieds one of the study's most significant findings centres on the role of motivation. Children who scored high for intrinsic motivation, who enjoyed learning for its own sake, not only performed better in school, but were generally more likely to seek out challenges, work harder, accomplish goals, and experience personal satisfaction throughout life – even when their IQ scores were not indicative of innate ability. The Gottfrieds showed that the variance in achievement gaps goes beyond IQ, and is correlated with motivated.

As Rebecca Haggerty puts it in her article on the Gottfrieds:

> "Overall, parents who encouraged inquisitiveness, independence, and effort, and who valued learning for its own sake, had kids with higher levels of intrinsic motivation and achievement. Further, the effects of these practices lingered as the kids grew older … The findings echo those of other experts. In study after study, external rewards like money or status tend to lower people's enjoyment of an activity, even if they previously liked doing it. So in order to set kids up for genuine success in life, they need to be intrinsically motivated—that is, to see learning and taking on new challenges as its own reward. "Teaching the desire to learn," the Gottfrieds wrote in 2008, "may be as important as teaching academic skills."
> - Rebecca Haggerty

('Highly motivated kids have a greater advantage in life than kids with a high IQ' in *Quartz*, December 2017: https://qz.com/1160024/highly-motivated-kids-have-a-greater-advantage-in-life-than-kids-with-a-high-iq/?mc_cid=f3788bde95&mc_eid=208eb831b9)

This resonates with psychologist Angela Duckworth's concept of "grit" and Stanford psychologist Carol Dweck's notion of a "growth mindset"– showing that a child's ability to persevere with a challenge despite obstacles (rather than innate ability) is predictive of success.

Growth mindset

What predispositions did Ben Underwood have that enabled him to navigate his world through clicking? He was intrinsically motivated (enabled by his mother's confidence in him and her decision not to be over-protective). He had grit and a growth mindset that ensured he could persevere and adapt.

Intrinsic motivation cannot be nurtured if learners believe that who they are is fixed and that everything they are doing is just an expression of a given set of abilities that define them. Carol Dweck called this a "fixed mindset" (*Mindset: The New Psychology of Success*, 2006). A "fixed mindset" believes that your personality, intellectual ability and creativity are permanent and unchanging aspects of yourself. Success becomes the quest to have these constants recognised and affirmed so that you know you are succeeding. Failure is avoided, because it can be experienced as a wholly defining moment, completely undermining what you are. Risk and effort, which have the potential to expose your weaknesses, are avoided.

A "growth mindset," on the other hand, thrives on challenge and sees failure as an opportunity to learn more about the growing edges you want to explore and develop further. With a growth mindset learners are motivated to make an effort to explore and learn. The effort feels satisfying and can be sustained even in the face of failure that requires the learner to reassess their strategy and what they know. In this way, instead of hungering for approval and affirmation in a fixed mindset, you develop a passion for learning things that can help you choose and invent who you want to be.

Praising learners for their ability not only labels them (even if it seems positive) but also tends to affirm a fixed mindset. Put yourself in the learner's position. Once you have been praised based on your ability you tend to protect that label, avoiding challenges that could contradict it. You might also become too quick to judge yourself, and label yourself as deficient when you do not live up to that label. Praising leaners for their effort, on the other hand, affirms a growth mindset, in which they move with curiosity and enthusiasm towards their growing edges and may even revel in the learning experience.

Learners with a fixed mindset find it difficult to deal with even minor discrepancies in their expectations of themselves, others and the world. They are more likely to deal with conflict by blaming others (or accepting blame and being paralysed by guilt) and ascribing some fundamental and fixed flaw to those they blame. Learners with a growth mindset are more capable of integrating new and challenging information about themselves, their relationships and the world around them. They recognise that we are all on a learning journey and capable of change. This makes them more likely to collaborate and participate in productive dialogue.

Do marks, the ranking of learners and award ceremonies affirm a fixed mindset or a growth mindset? Extrinsic rewards, like marks gained through standardised tests, are labels that tend to reinforce fixed mindsets. If they affirmed a growth mindset the highest awards would be given to those who had changed the most, regardless of their final score or comparisons with others learners. The open-endedness of approaches like project-based learning fosters a growth mindset exploring and experimenting with possibility – lingering in the learning for as long as possible.

When the system we are working in is so focused on extrinsic rewards and punishments, we tend to become suspicious of a learner's ability to be intrinsically motivated to do anything. We begin to think of learners as lazy and incompetent, but learning and working are naturally satisfying. We have inherited the idea that work is supposed to be boring and painful. Work is so easily seen as an obligation to someone else rather than a self-satisfying act of critical and creative self-expression.

Collaboration

By privileging individual rote memory we also affirm the misconception that exceptional ability is individual rather than the product of collaboration between diverse abilities and perspectives – collective intelligence.

It is our ability to share and compare our insights about the nature of reality (and disagree) that gives us the real power of knowledge creation. The ability to participate in productive dialogue, where collective memory is co-constructed and critiqued, is vital.

Some educators make a distinction between *cooperation*, in which the labour is divided between participants (and participants passively accept this – often reluctantly), and *collaboration* in which all participants are involved in the same task and are equally responsible for the output of the whole product.

Project-based learning offers opportunities for collaboration in which all participants are involved in the same task and are equally responsible for the output of the whole product. During real collaboration there is a more intense interaction between participants and need for constant negotiation. Collaboration creates opportunities for learners to engage disagreements more fully, and develop their critical thinking skills. In particular, we encourage learners to come to an agreement on the criteria for mutually beneficial disagreement. This is an opportunity for learners to uncover knowledge together, negotiate a learning path or strategy, interrogate each other's points of view, respond to probing questions, deal with feedback, and even correct each other's misconceptions. Furthermore, this is the kind of learning they will encounter in excellent tertiary education learning environments and in creative workspaces.

Building resilience – through trial-and-error learning

Nassim Nicholas Taleb is interested in what we do when we cannot predict what is going to happen next. Rote memory and accurate recall doesn't help us here. Instead of fearing change, Taleb suggests that we can learn to become more responsive to it. In his book *Antifragile: Things That Gain from Disorder* (2012) he describes a disposition that he calls "antifragile." The opposite of being afraid and fragile is not being tough and resistant, but being able to adapt to change, and more than that, being able to benefit from the changes around you – being antifragile. An antifragile system improves from exposure to stressors.

In everyday life people engage complex social, economic and ecological systems that cannot easily be reduced to a few variables. Accurate predictions can only be made when there are a few known variables with relationships that are understood. An antifragile system doesn't try to make accurate predictions. Instead, it is responsive to feedback, takes advantage of unexpected opportunities and benefits from trial and error experience. It takes small reasonable risks in regular of experiments. Many of today's successful business start-ups prove that self-confidence, the ability to overcome the fear of failure, intrinsic motivation, perseverance, imagination, re-appropriation of old ideas, recognising and seizing unplanned opportunities, and the ability to collaborate, are far more important than what was learnt, or even reinforced as a valuable disposition, at school or university. Children with rote memory skills are ranked highly in our schools, but this ignores the performative nature of learning in an ecosystem and actually disadvantages those children in the long run.

> "Some can be more intelligent than others in a structured environment – in fact school has a selection bias as it favors those quicker in such an environment, and like anything competitive, at the expense of performance outside it. Although I was not yet familiar with gyms, my idea of knowledge was as follows. People who build their strength using these modern expensive gym
> can lift extremely large weights, show great numbers and develop impressive-looking muscles, but fail to lift a stone; they get completely hammered in a street fight by someone trained in more disorderly settings. Their strength is extremely domain-specific and their domain doesn't exist outside of ludic – extremely organized – constructs. In fact their strength, as with over-specialized athletes, is the result of a deformity."
> - Nassim Nicholas Taleb, *Antifragile: Things That Gain from Disorder* (2012)

This poster was developed in collaboration between teaching staff at Sacred Heart College, MindBurst Workshop and the artist Paul Emmanuel.

A new appreciation for project-based learning

Let's summarise what we have covered. We now know that the brain does not perceive reality directly or accurately. We also know that the brain does not learn by storing information (in the form of internal representations) like a computer. Organic memories are not the products of accurate recording, storage and retrieval. Instead they are performances, imperfect but highly adaptive re-enactments and re-combinations of past performances that ensured survival. This re-membering applies the potential usefulness of old performance habits to new experiments, in response to whatever is happening now, and in anticipation of what is going to happen next.

The computer metaphor of the brain is becoming obsolete. An ecosystem may be a more effective metaphor for what happens when we remember, because it speaks to relationships between performances, which mutually influence each other through feedback.

Project-based learning harnesses the insights above to create safe enough opportunities for learners to learn how to:

- work things out on their own through trial-and-error performance,
- without fearing failure,
- while being willing to risk lots of small reasonable experiments,
- open to the information around them, able to reassess habits and goals in the light of new information and take advantage of unexpected opportunities,
- responsive to feedback and actively engaging disagreement (not because they are trying to win an argument, but because they are genuinely trying to understand what is going on), and
- able to adapt with as little anxiety as possible.

A learner with these kinds of attitudes develops a kind of ecological intelligence and thinks systemically, stepping back and being able to read the relationships between things and how they change each other over time. This kind of learner also perseveres and lingers in the learning experience long enough to create multiple 'rough drafts' that integrate new creative connections and critical feedback. This kind of learner is more resilient in life than a learner who can memorise prescribed material and get good grades in standardised tests.

One of the crises we are experiencing in our educational institutions is that we have over-valued obedient learners who can memorise the predictable order and get good grades. Research is starting to confirm that good grades don't correlate with long-term success. Pressure to get good grades also takes a toll on wellbeing, causes unreasonable anxiety, encourages cheating, and discourages risk and creativity.

(See: https://www.theatlantic.com/video/index/547163/perfect-grades-dont-matter/)

Don't do a job machines can do better than you

The power of the technology of printing, and now the digital medium, is that it does things brains cannot do very well. Stop and contemplate this for a moment. Books and computers store and stabilise information long enough for us to engage it, reflect on it, criticise it, amend it and build onto it. This is why these technologies have made such a radical difference to our ability to create, share and contest knowledge. If they store memories better than us, why are we still trying to turn learners into a living version of textbooks and computers?

Machines outperform humans in tasks that require rote memory or the faithful reproduction of step-by-step procedures. Learners need to be able to choose jobs that machines will not do better than them. Graduating from school with the skills of a poor computer is not a strategy for thriving in the 21st century.

Machines are already moving beyond rote memory or step-by-step procedures towards learning through experience. This is because developers of artificial intelligence (AI) are using insights from brain studies to enable machines to learn. The old way of programming AI was taking what people already knew and then coding it into the AI (pretty much how most teaching in schools still works). The way that artificial neural nets now learn is through active experimentation, constrained by clear outcomes. In other words, they are told what they need to achieve, and then find their own way of achieving it through trial and error.

While computers are much faster than us they are not yet as creative or complex as us. The skills that they learn are still very narrow and specific. There is a debate as to whether machines will graduate from domain specific intelligence (identifying cancer cells on a slide or transcribing voice into text), where they tend to out-perform humans, to more multi-purpose general intelligence which links all the domain specific intelligences together.

We need to recognise that what machines will soon be capable of may be beyond our imagination. For now, we could say that we need to be learning the skills that machines are currently poor at: critical thinking, creative innovation, clear communication and dynamic collaboration.

Wasted effort

Universities keep telling us that the matric exam gives no indication of how a learner will perform at university. There is no correlation at all – except perhaps for individual learners who have succeeded against all odds at poorly resourced schools. How does the matric exam prepare learners for life? We really have to think about this seriously, because we are taking a few years of a young person's life, when their brains are at their most dynamic and adaptive, capable of abstract and complex thinking, and we are using it to coach them (not educate them) for an exam that doesn't seem to offer much. It doesn't prepare them at all for the kinds of critical and creative thinking that are now being valued by the knowledge economy. The matric exam is even less useful in preparing them for a meaningful and satisfying life. Shouldn't we rather be spending some of that time enabling them to be more creative and critical human beings?

How can we:

- focus less on content and more on the creative, critical, communication and collaboration skills that are required to deal with any content;

- instruct less and help learners discover and build knowledge from the bottom up, rather than just being instructed by an 'expert';

- blur the boundaries between subjects and experiment with integrated studies in which learners can discover the deep structures that different knowledge systems share in common, encouraging systemic thinking;

- bring productive dialogue and democratic processes into the classroom and school culture, giving learners more say in what and how they learn;

- experiment by not assessing memory and focusing on assessing understanding, application and transferable skills?

In conclusion

All our perceptions of reality exist somewhere on a continuum between being a useful hypothesis and a delusion. The main difference between a hypothesis and a delusion is that a hypothesis is open to new information that may challenge and change it and a delusion is not. This is where critical thinking skills compliment creativity. It could be said that the most potent combination of creativity and critical thinking is the scientific experiment. Trial-and-error learning explores the same dynamics that are formalised in the scientific method. Growing knowledge has a lot to do with allowing our hypotheses to be questioned when we are confronted with information to the contrary (through dialogue or personal experience). We need to reframe failure. That is hard to do when we are still expecting correct answers from our learners and ranking them according to their ability to do what fits our predictable expectations.

The path to success is no longer the linear and singular path that parents and teachers envisaged for themselves. The future belongs to shape-shifting, multi-disciplinary, highly adaptive, life-long learners; resilient problem-solvers who are not afraid of failure; risk-taking experimenters; technology-literate knowledge workers; maverick innovators that can break their society's thinking habits; critical consumers; active citizens; ethical hackers; and independent thinkers.