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. Psychology has 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 Hermann Ebbinghaus forgetting curve.

It is possible to cram and, with clever mnemonics and other memory tricks, get a distinction without understanding much. How useful is that skill? We reward children for cramming, but how is this preparing them for a meaningful, sustainable and satisfying life?

Our education system often confuses what is in the textbook with what we think needs to be in a learner's head. We tend to teach children about the world by emphasising the accurate memorisation of abstract information. 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 paper 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.

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?

If you dispute that this is what we have been trying to do, ask yourself what assessments would look like if we stopped assessing memory altogether. I am not suggesting memory isn't important at all. I am merely highlighting that 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.

The ability to memorise information or faithfully reproduce a procedure is something computers do far better than us. Graduating from school with the skills of a poor computer is not a strategy for thriving in the 21st century.

Neuroscientists tell us that the human brain cannot store memories at all! This is a very counterintuitive idea. The old information processing computer metaphor gets memory wrong. This has huge implications for the way we teach and is the main idea that we will explore in this article.

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. Are we willing to teach things we cannot easily assess?

Leading educators and educational institutions all in 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. We need to go beyond prescribed content and teach learners how to engage any content, so that they can become active agents of their own knowledge production. Transferable skills are those critical, creative and collaborative thinking skills that are required to deal with any content. Identifying the transferable skills can be a challenge when you are so used to focusing on content. But making a concerted effort to express these skills clearly will help you to plan effectively, as everything else depends on knowing what transferable skills you will be exploring, affirming and assessing. This requires a focus on "how to think" rather than "what to think."

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.

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)

Reflect on this story and ask yourself 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 – an experiment. Some of our experiments succeed in teasing reality into revealing itself, whether that is the reality of our own bodies or the world "out there". We call this feedback. Some of that feedback positively reinforces our performance and that performance becomes a useful habit. 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. It challenges the popular perception of learning as the passive process of receiving predesigned knowledge from a teacher or an expert.

We have no direct access to, or an 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 we perceive the world. The first point that Lotto makes about perception is that we do not have direct access to, or an accurate experience of, reality. Our sense organs pick up very little of the available information. Not only that, but the limited amount of information that is received by your sense organs never reach consciousness.

Your sense organs translate the information they receive into electro-chemical signals. These electro-chemical signals then get translated into what you experience as smells, taste, colour, sounds, 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 (electro magnetic 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 electro magnetic 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 the electro-chemical 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 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, it is reinforced – the organism lives and reproduces other organisms with predispositions for similar performances. An un-useful 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, to perform actions and reactions. Initially, at least, since no organism could perceive anything in itself, the usefulness or un-usefulness, performance in response to stimuli (information that acts on the organism) was a coincidence.

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 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."

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 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.

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".

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 talk about neural performances (informed by ecological psychology and dynamical systems theory) 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.

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.

Predicting the future

Lotto's intellectual predecessor was Richard Gregory. In *Eye and Brain* (1966), Richard Gregory described all perception as hypotheses. 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 and activate the motor system (physical performance).

Growing knowledge has a lot to do with allowing our hypotheses to be questioned when we experience information to the contrary. This is the basic difference between a hypothesis and a delusion. All our perceptions of reality exist somewhere on a continuum between being a hypothesis and being 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 dynamics that are formalised in the scientific method.

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 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. The resulting web of associations may not look like anything you have experienced before. If it does feel like something you have experienced before there is actually no way you are able to tell – 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.

The components that you associate in this process of remembering (as we are reminded by the constant refrain in this article) are not coherent internal representations but neural performances. These neural performances are patterns of electro-chemical activity between neurons (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. While we know a lot about how neurons work, we are still not entirely sure how they give rise to subjective experience.

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 desire. 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 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)

Fortunately, 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)

Being antifragile

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 predictable relationships. 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 lots 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 education system, 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 machines 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)

One of the crises we are experiencing in our educational institutions is that we value 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/)

Collaboration

By privileging individual 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 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.

During real collaboration there is a more intense interaction between participants and the need for constant negotiation. Collaboration creates opportunities for learners to engage disagreements and, in so doing, 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.

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 and doing into the learning experience of all children, meaningfully including a greater diversity of children in the process?

Building resilience – through trial-and-error 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 these insights to create safe enough opportunities for learners to learn how to work things out on their own through trial-and-error learning. The learner who benefits from trial-and-error learning can develop a kind of ecological intelligence that:

- thinks systemically – stepping back and able to read the relationships between things and how they change each other over time;
- is open to the information around them;
- does not fear failure;
- risks lots of small reasonable experiments;
- is responsive to feedback and actively engages disagreement (not because they are trying to win an argument, but because they are genuinely trying to understand what is going on);
- perseveres and lingers in the learning experience long enough to create multiple 'rough drafts' that integrate critical feedback;

- who takes advantage of unexpected opportunities;
- is able to reassess habits and goals in the light of new information; and
- adapts to change with as little anxiety as possible.

This kind of learner is more resilient in life than a learner who can memorise prescribed material and get good grades in standardised tests.

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. If we had to apply the contemporary understanding of memory to it, all the thinking skills would be forms of associative memory.

How teaching neglects the "how" in favour of the "what"

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) explores how people separate provisional scientific truth from myth. They showed that that having a strong scientific knowledge base is not enough to insulate a person against irrational beliefs. This is part of an increasing number of research studies showing that we cannot assume critical thinking is being learnt during science classes.

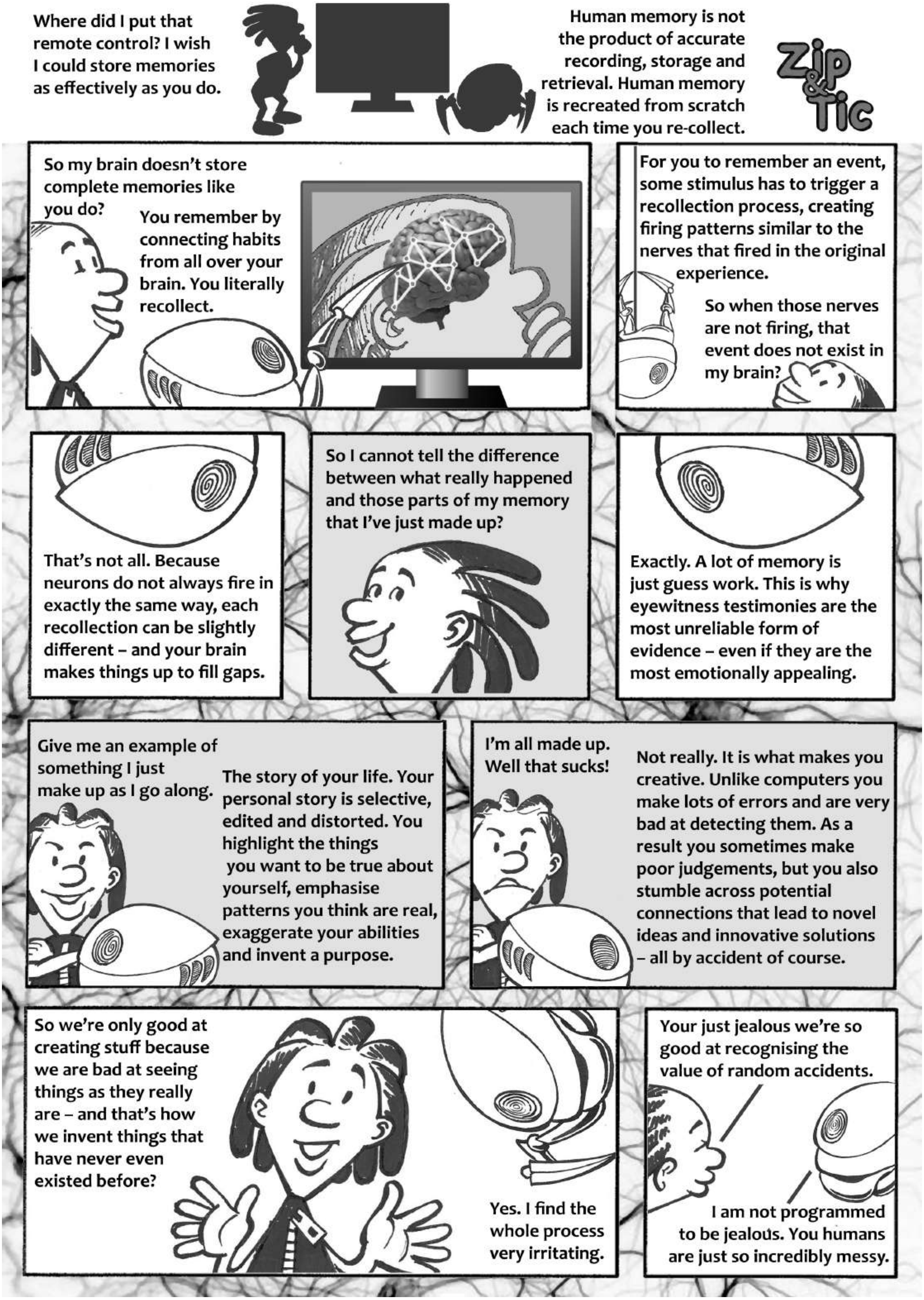
The researchers say, "We suggest that this inability stems in part from the way that science is traditionally presented to students: Students are taught *what* to think but not *how* to think."

Their analysis of 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 skepticism. 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."

Wasted effort

Why are we spending all these critical years of a young person's life, when their brains are at their most dynamic and adaptive, capable of abstract and complex thinking, coaching them to be poor computers? So much energy is spent preparing them for an exam that has been shown to offer little indication of whether they will succeed at university and doesn't prepare them at all for the kinds of critical and creative thinking that are now being valued by universities and 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?

The future belongs to technology-literate knowledge workers; resilient problem-solvers who are not afraid of failure; risk-taking experimenters; maverick innovators that can break their society's thinking habits; critical consumers; active citizens; ethical hackers; and independent thinkers.



Where did I put that remote control? I wish I could store memories as effectively as you do.
Human memory is not the product of accurate recording, storage and retrieval. Human memory is recreated from scratch each time you re-collect.
Zip & Tic
So my brain doesn't store complete memories like you do?
You remember by connecting habits from all over your brain. You literally recollect.
For you to remember an event, some stimulus has to trigger a recollection process, creating firing patterns similar to the nerves that fired in the original experience.
So when those nerves are not firing, that event does not exist in my brain?
That's not all. Because neurons do not always fire in exactly the same way, each recollection can be slightly different – and your brain makes things up to fill gaps.
So I cannot tell the difference between what really happened and those parts of my memory that I've just made up?
Exactly. A lot of memory is just guess work. This is why eyewitness testimonies are the most unreliable form of evidence – even if they are the most emotionally appealing.
Give me an example of something I just make up as I go along.
The story of your life. Your personal story is selective, edited and distorted. You highlight the things you want to be true about yourself, emphasise patterns you think are real, exaggerate your abilities and invent a purpose.
I'm all made up. Well that sucks!
Not really. It is what makes you creative. Unlike computers you make lots of errors and are very bad at detecting them. As a result you sometimes make poor judgements, but you also stumble across potential connections that lead to novel ideas and innovative solutions – all by accident of course.
So we're only good at creating stuff because we are bad at seeing things as they really are – and that's how we invent things that have never even existed before?
Yes. I find the whole process very irritating.
Your just jealous we're so good at recognising the value of random accidents.
I am not programmed to be jealous. You humans are just so incredibly messy.

A few words about machine learning

The machines that are currently out-performing humans are doing it through trial-and-error learning and not through memorisation.

The old way of programming AI was taking what people already knew and then coding it into the AI. This is pretty much how most teaching 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. The programmer never explicitly gives the computer an algorithm for the task. The computer creates its own algorithm in an iterative learning process. The fact that they can run many experiments in quick succession gives them an advantage over humans. While they are faster than us they are not yet as creative as us. An added twist to machine learning is that machines that can learn can teach each other. One machine can instantly inherit the experience of another, combining accurate information storage with trial-and-error learning, something humans cannot do.

Automation is quickly replacing humans in the kinds of jobs where the skill of memorisation is required. A January 2017 report from the McKinsey Global Institute estimated that roughly half of today's work activities could be automated by 2055, give or take 20 years. Knitting was one of the first tasks to be automated, but today such complex tasks as driving a car, conducting scientific experiments or reading handwriting can all be automated. Self-driving cars that can see 360°, and don't get hungry, angry, tired or horny will replace millions of drivers all over the world. But we're not just talking about replacing long-distance truck drivers, miners, factory workers, farm labourers, domestic workers, tellers and clerks – we're talking about machines that can do the work of bookkeepers, website designers, journalists, paralegals (identifying and collating legal precedents), and pharmacists (checking prescriptions against the medicines a client is already taking). Machines are already capable of making better investments than most humans trained to be investors. Algorithms perform more than 70% of financial trading across the world. Bridgewater Associates, the world's largest hedge fund, is developing algorithms to automate management decisions, including the hiring and firing of employees. AI bots created by companies such as Narrative Science and Automated Insights write business and sports stories for clients like Forbes and the Associated Press. Human-like "social robots" teach children on the autism spectrum appropriate social behaviour. Therapeutic robot pets provide companionship for seniors with dementia. The US military uses a computer-generated virtual therapist to screen soldiers for PTSD. New visual recognition software allows machines to diagnose and describe rare cancers with greater accuracy than most doctors.

How are we going to prepare learners for meaningful, satisfying and sustainable lives in a world where technology is fundamentally transforming learning, work, play and wellbeing? We could say that we need to be teaching them the skills that machines are currently poor at, like systemic thinking, creativity, emotional intelligence, managing teams, activism and education. We also need to recognise that what machines will soon be capable of may be beyond our imagination.

André Croucamp works with MindBurst Workshop designing and facilitating critical thinking skills interventions, project-based learning and integrated studies in schools.

MindBurst's pilot projects were hosted by Sacred Heart College from 2013, but their activities have spread to many other schools since then. André also collaborates with the Head of Sacred Heart College, Colin Northmore, to set the IEB exam on thinking skills.

The MindBurst team is known for their ability to create meaningful and immersive learning experiences like:

- Grade 4s creating zig zag comic books (leporellos) to practice the art of creating of narrative;
- Junior High learners creating life in miniature, by designing the interior of the spaceships that will take humanity to the stars;
- Grade 10 learners working in Crime Scene Investigation teams, grappling with evidence, while analysing the garbage of a suspect; and
- Grade 11s throwing the bones to explore complexity and innovation as part of decolonising education.

MindBurst also works closely with the Three2Six Education Project facilitating week-long creative thinking skills courses for refugees between the ages of 6 and 13. They have helped the children produce, books, exhibitions, a musical theatre production and stop frame animations that tell their stories.

Andre's first degree was in Theology at Rhodes University. He later completed his Masters in Cognitive Archaeology at Wits.

For most of his life he has worked as an educational media developer producing comic books, games, textbooks and documentaries. His most recent academic paper 'The Natal Government Railways and their Production of 'the Zulus'' appeared in the publication, *Tribing and Untribing the Archives*. The journal *Choice*, which provides book reviews for academic libraries, has picked the publication for the 2017 Outstanding Academic Title list.

André designs and develops museums all over the country like the Woza eNanda Heritage Route in KwaZulu-Natal and the Moruleng Cultural Precinct in North West Province. You may have visited Liliesleaf or the Origins Centre locally, which contain many exhibitions he has created together with Totem Media. Their most recent exhibition is *Unthreading Mandela*, a critical reflection of Mandela's legacy. It can be seen at the Nelson Mandela Foundation.