Neuroscience and Education: How Can We Play, Learn and Be More Creative?

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Introduction

One part of my background, which I think wasn't touched upon, but I'm very proud about, is that I was also a schoolteacher for a number of years, and for another 7 or 8 years after that I trained primary school teachers and secondary school teachers, inspected schools and then became a psychologist and then became a neuroscientist, but all the time very much being concerned in my thoughts and in my feelings about the importance of education and still what happens in the classroom is the thing which is of most importance to me, even though I spend most of my time now doing research – some of that research is in the classroom, some of that research is using neuroimaging, looking inside the brain.

So I suppose that explains how I became so closely involved in this new adventure of joining neuroscience and education together and I'm here tonight, in a way, to try to persuade you that neuroscience and education do belong together, they need to talk to each other, we need an authentic dialogue that can be of benefit to both fields, but most importantly to our children.

This talk is divided into two parts. The first part is about neuro-myths, the second part is about authentic ways in which neuroscience can support and illuminate education. These are my two basic arguments, really, that if neuroscience does not get involved with education and if educators do not learn about neuroscience we're going to have more neuro-myth. So an important part about having an authentic dialogue is to get rid of the neuro-myth and the other important thing about a dialogue will be to introduce new ideas about how we learn which can really make teaching and learning more effective, more productive.

Neuro-myths

So let me say a little about neuro-myth. It's not surprising that teachers are interested in ideas about the brain. We did this survey a few years ago, 90% of teachers think that it's important or very important in the design of educational programmes. I think that reflects a natural enthusiasm and it is natural, it should be natural because teachers are the only professionals who on a daily basis are responsible for changing the function, the connectivity and even the structure of the brain because when you learn something and you practice something long enough it actually changes the shape of the different regions of the brain and there's only one professional who's responsible for doing that on a daily basis and that is the teacher, so it is natural that teachers should be interested. But of course that also makes it possible for that enthusiasm to be exploited and sometimes for misunderstandings to occur.

So in the Nature paper that I published recently we put together a whole series of data that we'd collected from different countries to find out how widespread some of these neuro-myths are and all of these things on the left hand side here are false and this gives you the distribution of how many teachers in these different countries believe in them and you can see that we only use 10% of our brain almost half of teachers in all of those countries believe that, but of course we use all of our brain all the time, all of the brain is processing and if you ever have a part of the brain which is not functioning then you have a serious medical condition!

This however is probably the most virulent and in a way one of the most damaging ideas in education, that we have a method of categorizing learners in terms of a particular learning style and if you teach to that learning style then they are going to learn more efficiently. We do have methods of categorizing learners, in fact there are over 80 different surveys that you can download from the internet or you can buy, these self-report surveys that you give to the student, they fill them in and they find out that they are a visual or auditory or kinaesthetic learner.

The number of these tests is growing all the time. The latest one is how much of a boy learner or how much of a girl learner you are, how male or female your brain is irrespective of your gender and then once you've filled in that survey there is a variety of products that you can buy that are going to support your learning.

Now unfortunately none of these inventories, none of these surveys have ever shown themselves to be effective in terms of educational research, that's what the educational research says, there's no educational benefit in knowing somebody's learning style of any type and the psychological experiments that have been undertaken have confirmed that and even shown that there's sometimes benefit in receiving information in a style that is not your preferred learning style.

The neuroscience tells us that the brain is so interconnected that such an idea of categorizing people in terms of left or right brain or visual or auditory, kinaesthetic is a bad starting point, because in terms of the biology it doesn't make sense. Nevertheless we also have other learning styles like down here, hemispheric dominance, left or right, helps explain individual differences, whether you're left brained or right brained is another very popular idea which doesn't really help you as an educator.

This is from Brain Gym, the idea that if you carry out coordination exercises or if you rub your brain buttons it will integrate your left and right hemisphere. There's really no support for the effectiveness of that approach, yet you can see it's very popular across all of these different countries.

And some of these things sort of make sense in so far as they resonate with our suspicions and we see children coming in having had sugary snacks or drinks and they appear to be misbehaving and so we think it's making them less attentive, but actually sugary snacks and drinks can make you more attentive for a little while, the real problem with them is that they rot your teeth, that's the real problem.

This is one which is particularly popular in Britain, I don't know why, I think it's because we've been sold a lot of water products on the basis that they're good for your brain, but 30% of our teachers think the brain will shrink if you don't have 6 to 8 glasses of water a day.

But this one at the bottom, although we only have a few teachers that believe in it, a lot more in China, this is more insidious, it's more sinister as a neuro-myth, this idea that learning problems linked to brain differences cannot be remediated by education, that suggests that if you have a diagnosis of dyslexia or dyscalculia, which we know are linked to brain differences, that that means they are biologically determined and there is nothing you can do about them.

So how teachers think about brain development in terms of the genetic contribution influences their attitude in the classroom and that's why I feel it's really important for teachers to know more about how the brain develops and the role of genetics and the role of the environment, and the most important part of the environment, if you ask me, is the school, how that influences brain development.

So this is a very quick anatomy lesson, it's not going to get very complex, but I just wanted to show you that, yes, there are regions that are associated with different modalities, so your somatosensory strip is here and that's very important for feeling, the auditory cortex, very important for processing sound, the visual cortex very important for processing visual information, but the brain is massively interconnected so if you see a picture of a bell your auditory cortex activates, because you're almost imagining that you're hearing that sound, maybe, I don't know, but it's very interconnected. It's very difficult to talk about how one brain region operates completely independently of other parts of the network that it's connected to – and all the brain is active all the time.

If you take a slice through the brain, what we call a sagittal slice through the brain, and you have a look inside you'll see that there is a very familiar tripartite structure, familiar in the sense that if you look at other brains you'll see three very similar partitions to the brain, the forebrain, the midbrain and the hindbrain.

There is another myth that these parts have developed through evolution so that if you look at reptiles they don't have this sort of cortex and therefore we call this the reptilian brain, but I feel this is not true. The invertebrate has had this tripartite structure for 500 million years, ever since fishes evolved and actually the midbrain, for example, and the hindbrain, are very connected to the forebrain in a sophisticated way and when you make decisions, for example, whether you're going to a restaurant, you might be looking at the prices and do some difficult calculations and maybe that's going to take some parietal cortex or whatever, but actually your reward system which very much depends on the midbrain is going to be activating as well and it's very important for you making those higher level decisions.

The other thing I wanted to show you here is that the corpus callosum connects the two hemispheres together, so this idea that you can be left brained and you just use the left brain is really artificial because both halves of the brain are talking to each other through this information superhighway all the time.

So what's good and bad for brains?

There's a lot of discussion on this and a lot of products that are sold on the basis that they're good for your brain. We have a lot of newspaper articles in the UK about the importance of water and in fact in one brain-based book they encourage children to sing to the tune of *Frère Jacques* "let's drink water, I love water, it gives me, energy.' – this idea is that the more water you drink, the better you're going to get at your school work and there is a sort of neurosis in the UK, you quite often see mums chasing after children with their water bottles to make sure they drink enough.

Well, it is true that 80% of our brain is water. It's true that mild dehydration can decrease your ability to think, that drinking too little water can be dangerous and even result in death and that people do feel more attentive after a drink of water and there's a popular idea that we need to drink 6 to 8 glasses of water a day, we don't really know where this figure has come from. However, *feeling* more attentive is not the same as *being* more attentive.

Research done at our university has also shown that drinking water when you're not thirsty can also reduce your ability to think and there is also evidence, particularly amongst children with special educational needs, that it is possible to drink too much water and sometimes, sadly, that can be fatal as well.

So you're now thinking should I drink too much, too little and maybe you feel on a tightrope about this, but luckily we have brains that have regions in them that help us control our bodily stasis, our stability, and we know unless it's particularly hot or unless we're undertaking exercise, we know when we need water because we feel thirsty. That's a function of the brain that makes us feel like that.

In fact it's very difficult to find evidence of where children have become voluntarily dehydrated when there is water actually available to them. And it is really important that children have available a good quality source of water that they can draw upon, but the only evidence that you can find in the literature of when children have voluntarily dehydrated is in the Dead Sea region, which is one of the hottest regions of the world.

So it is possible that your brain can shrink, there is some evidence that after a lot of exercise the ventricles which do not contain grey matter expand but it's not linked to any change in cognitive function, the only really serious case we have of documented brain shrinkage that I can find is a man in Japan who tried to commit suicide by drinking too much soy sauce, a quite unusual case I would imagine. They found that his brain shrunk, but after 3 months of carefully rehydrating this poor man, they found that the brain returned almost to its original size.

I don't know if you know what this is, but all these people here are doing something called Brain Gym, which is quite popular in a number of countries and these sorts of coordination exercises, actually there's a lot of programmes that use this sort of coordination exercises. They're not particularly aerobic, they're not getting your heart racing, but there's a belief that by coordinating your thoughts and your hand movements that this is going to support your education, your literacy in particular.

In Brain Gym, for example, you're encouraged to rub two buttons that are supposed to be here and that's going to integrate your left and right hemispheres, but it's kind of like rubbing the radiator to fix your central heating, there's no process that can really enable that to happen. There's no physiology that can explain how such a thing could occur. Nevertheless it's incredibly popular.

Omega 3 is something else which is sold to us on the basis that it can make us clever. So you can have clever bread and clever milk. Our BBC also picked up these stories and tells us that Elliot, for example, is now reading lots of Harry Potter books because he is taking fish oils, the common way of getting Omega 3 and there's a lot of circumstantial evidence to show that Omega 3 is very important for us, but unfortunately that evidence is more about before birth, so mothers who eat a lot of fish can produce children with higher IQs, but that's not the same as meaning that if you take these supplements it's going to make you more clever because it takes a very long time to reach your brain and there are mixed results from giving supplements to children with some developmental disorders, so that's interesting if we're getting mixed results its worth looking closer, but amongst the general population, amongst those who are not diagnosed with any particular disorder, there are very little effects, it's very difficult to find any affects that could confidently tell you that you're going to be more clever if you take more Omega 3, sadly.

And of course a lot of these things are very attractive because they're so easy to do. It's wishful thinking and we're attracted to things that are easy, easy fixes.

Learning styles again, and I've talked about this already, very popular amongst teachers, no evidence for educational benefits despite many, many studies. No basis in neuroscience and the scientists have really declared that this is wasted effort from the psychological studies that have been done.

Caffeine, there is a myth that caffeine can wake you up, but actually if you're not a caffeine user then possibly it can, but unfortunately once you become a regular user of caffeine it actually suppresses your cognitive function and a regular user of caffeine includes children who drink only two cans a day of soft drinks and sometimes they're colas, but there are other drinks that contain caffeine as well and that means that if you're a coffee drinker or if a child is drinking two cans of cola a day that their cognitive function only goes up to normal when they've had their fix of caffeine and the rest of the time it's actually suppressed.

So we commonly see symptoms of caffeine withdrawal in children and you may have experienced them yourself as an adult. You get the headaches, sleepiness and it's something we possibly need to take more seriously, especially now we have these very highly caffeinated drinks and one of these, for example, is equivalent to about 3 cups of coffee so you only need to be having one of those a day to be feeling the effect of that cognitive suppression.

However some of the things, as I've already mentioned, that really worry me are more subtle issues and it's not just teachers that suffer neuro-myths it's also educational policymakers as well. And for a long time we have begun to take more seriously the importance of early years education, as we should have done, because for many decades we did not understand how important the early years are.

Authentic ways in which neuroscience can support and illuminate education

However in the last 10 years or so neuroscience has been used to make that case economically in terms of where funds should go and sometimes the neuroscience has been used to produce very simple graphs like this about the return on investment in education and what this graph is telling you here, this is the return per marginal pound, euro, dollar, whatever and it's basically saying, look, after the age of 3 it's hardly worth investing in a child.

Now that is not a good message and you can see it very clearly because what people are saying in this graph is look, this is where we're putting our money and this is the return you get economically from an equation that is supposed to be based on neuroscience and neuroscience cannot support that sort of model. The neuroscience that is being used draws on the idea of the sensitive window of development. Now we do have sensitive windows of development, for example before the age of 1 if you have not heard particular sounds you will find it more difficult to identify them and to learn them. It took me a long time to learn Russian because there are sounds in Russian I never heard as a baby, but I could do it eventually.

So there are windows of sensitivity in terms of language development, but these windows that we know about involve quite primary function such as perception and motor functions and it is highly likely that there are also sensitive windows during adolescence but these are going to involve much more complex functions for example identity seems a highly likely one and we can see from the circumstantial evidence in the neuroscience that these windows are highly likely to exist, but we don't really have the methodologies and techniques to identify them. We've been more successful at finding these sensitive windows amongst younger children.

So the message is that all of childhood up until the late teenage years is actually a special time for learning and it is not possible to say that interventions should always be earlier it depends what the intervention is and whom the intervention is targeting.

Generally speaking if you're talking about cognitive function and children who are disadvantaged or children who are suffering a developmental disorder or who have difficulties then that is probably a good time to be doing an intervention, but other interventions, for example, risk taking, which can be a serious problem amongst teenagers doesn't make sense if we're thinking about that as the earlier the better, it just does not work.

So very often here you see this is a very influential think tank that advises our UK government and they're saying that the Heckman curve to which Allan himself refers shows that investment in early years education produces better returns. This curve shows that. No it doesn't. It's just a mathematical curve based on some very somewhat superficial reading of the neuroscience and we have to be careful about neuro-myths in government as well as amongst teachers and learners, I should say.

That curve has been incredibly influential in our policy making in Britain, this is showing you a riot that took place when they reduced funding for higher education in the UK and the minister at the time told me personally that this graph here is very influential in the sorts of discussions that take place about these sorts of issues.

So we have to be very careful about how we think about neuroscience when we come across an idea that claims to involve neuroscience there is usually some fact, all of these things are true. Learners do benefit from receiving information in a range of different modalities. That's scientifically and educationally sound. It's not true they benefit from being taught in their preferred learning style.

It's true that language is generally left lateralised so it tends to involve regions more on the left than on the right, but it doesn't mean that it's good categorising children as left-brained or right-brained.

It's true that dehydration can reduce cognitive functioning, but it doesn't mean that less than 6 to 8 glasses of water a day can cause the brain to shrink. I should say by the way that in situations of heat and, of course, in Spain you have many more of those than we do, and also in situations where there is exercise it is necessary to monitor children's drinking of water and that's important. In the UK schools sports days are very often held in the summer when both of those things are occurring. But generally speaking, in our sort of climate, certainly in the UK, worrying about whether you're having 6 to 8 glasses of water is not really appropriate.

Aerobic exercise is really good for the brain, but it's not true that rehearsing motor perception things, exercises are good.

It's true that the younger brain is more plastic, so that's a very important thing to remember, but actually our brains are plastic all through our lifetime and it is certainly not fixed at 3 years old, that is a myth that is commonly believed by many.

So my idea about how these things form is that you often do end up with these seeds, these little scientific seeds, but you have these massive weeds that are growing up and they are allowed to grow because we have this gap between neuroscience and education culturally that provides this fertile space in which these things can grow and what forms in that space is very much influenced by our biases, including emotional biases, because we just want it to be true, or our anxiety biases because we fear, for example, technology is taking us over so we develop myths sometimes about what Facebook is doing to our brains.

There is a warning here because neuroscience is very seductive and this was a study that was done by Weisberg and his team who put forward explanations to people without any neuroscience in them at all. Some were good, some were bad and you can see that participants can rate them as good or they can rate them as bad. We're looking at experts now, experts who should really know their stuff and they have no problem distinguishing between good or bad explanations for an effect and then they put in a relevant neuroscience and you'll see that the good explanations actually start to get rated badly because the scientists did not like irrelevant neuroscience in the explanation.

But look what happens with the general public and people who don't really know about neuroscience. They can also tell the difference between a good explanation and a bad explanation, but once you put in the irrelevant neuroscience and this neuroscience has nothing really to do with the explanation they've just put in a brain picture or they refer to the frontal cortex immediately these non-specialists begin to believe in this explanation.

So neuroscience has the ability to sell explanations and so we do have to be a little bit careful and if you hear somebody say, "oh it's based on neuroscience", don't say, "oh wow then it must be true", always say, "well who says? Are they a neuroscientist?" and you can follow that up with the question, "well where is it published", because I'm afraid even neuroscientists, particularly when they're off the record or talking to a journalist will sometimes say inappropriate things, particularly about education, I've noticed. So always say "are they a neuroscientist and where was it published".

Question about Multiple Intelligences

I've been asked about multiple intelligences. Multiple intelligences, the idea was created by Howard Gardner. His idea was to emphasise the multifaceted nature of human intelligence and that's a good thing and teachers like that idea and maybe it's a good thing to emphasise how people are different and how people have different abilities, different special things about how they think. I don't think he ever intended it to be turned into a learning style and very often you see multiple intelligences applied in this way.

So the idea that we should think about intelligence in a very many different forms I'm not particularly worried about, but when it starts being used as a basis for a learning style then there just isn't the evidence to show that it can work and I know that Howard Gardner never intended it to be used like that either.

Question about the Heckman Curve

My interpretation and my concerns about the Heckman curve have been published in *Developmental Science,* but before I published them I had the privilege and the honour to present the paper in front of James Heckman, which was quite worrying because I am a humble scientist and he's a Nobel prize winner. He was an absolute gentleman about it and he is also concerned at the way in which his work is interpreted and I have no problem with the economics of James Heckman, only the way in which his work has been interpreted and some of the ways it's being used by policy makers and I know that his heart is definitely in the right place and he has worked tirelessly to emphasise the importance of early years education.

Let's move on to authentic applications. I'm going to have to go quite quickly through these. I just want to convince you that there are some areas you need to be thinking about, things we know about already that are important.

Neuroscience has gone some way to emphasising that using your fingers in mathematics is not necessarily a bad thing. There was a time when we used to suppress children when they used their fingers, we now understand that in fact it's part of how cognition is embodied, we are designed to think in terms of action and in terms of our bodies and it's not a coincidence that we work in base ten, we have 10 fingers. We now have some interventions that show a better awareness of your fingers can actually support your early number development and that's an interesting step forward, I think.

We're also learning more about the underlying numerosity systems that we share with animals, this ability to estimate number very rapidly, automatically, may bootstrap our formal understanding of mathematics and so what you can see here are yellow regions where the adults use to approximate, but when they are asked to do an exact calculation they start to use more left lateralised language areas because they're using an inner dialogue to think through the processes involved.

The fact that we use these regions, particularly the intraparietal sulcus back here, to approximate is important because we are still trying to understand how children develop that first awareness of number and why sometimes it goes wrong and when we look at children who are having difficulties with number we are gaining insights from neuroscience about how there may be a core deficit in that number ability, in that ability to estimate number and there are now interventions which are showing some promise although I have to say there is still a massive debate about this.

Anxiety is another area, for example, we know that mild stress can actually be good for learning when it occurs in the same time and place externally and in the same time and space internally in the brain. When you're revising for your exams if you're a little bit worried about your learning, actually that can be a good thing, it can make it an emotional memory, make it easier to encode, but during an examination if you're mildly stressed, you're using more regions that are involved with working memory, that's your ability to hold information consciously in your attention and that will reduce your ability to perform in your examination and the more anxious you are the more this region activates and that's bad news because really you only want that region to activate because you're doing your academic work.

There are some interventions now, for example, writing about your anxiety prior to a test appears to remediate some of the problems in your performance associated with anxiety and these sorts of interventions have been prompted by a better understanding of the underlying processes between anxiety and academic performance.

I mentioned some interventions that have been shown to operate for mathematics and one of the most interesting things in this example children are being encouraged to represent their answers on a number line by landing the spaceship and giving a physical meaning to the number they are expressing and that improves number ability amongst children diagnosed with dyscalculia, which is a number disorder, but also amongst children without that diagnosis and as well as remediating their behaviour it also shows remediation of brain activities associated with that problem as well and so there's two important points here, apart from having some ideas for new interventions with children, it also tells us that, well it gives us some insight into the extent to which children with and without a diagnosed disorder should be categorized as qualitatively different, because actually both for dyslexia and dyscalculia the interentions that are being developed quite often work for all children, so that's kind of interesting and we could get into a discussion here about how meaningful some of these phrases are – ADHD, dyscalculia, dyslexia, but from my understanding and my reading of the literature I would say that there is very little neuroscience evidence or genetic evidence from the scientists to say that there is a qualitative difference in these behaviours.

Sometimes we look at pictures like this and we say oh look the children with and without dyscalculia have different brain activities, it must be a biologically determined disorder, but no actually these sorts of neuroscience studies are showing us how plastic the brain is and how influenced it can be by the correct intervention.

In reading we used to have dual root models whereby you would either use a visual system or you would use a phonological system to read, we understand more that the different ways of coding sound and letters and spelling are all interrelated in a very interconnected manner and all are likely to be firing simultaneously and informing each other because the brain is a massively parallel system and so the reading systems are distributed, they contain some redundancy, it gives us some ideas for interventions as well, understanding the different types of coding that have to occur and, excitingly, we find that we can use neuroimaging to explain how interventions operate a little bit like the mathematics study, we can see this one using a game called Graphagame which is encouraging children to link graphemes, the written form to the sounds, but after playing the game they are better at their phonological decoding and also again we see the brain activity is also becoming remediated and we almost have a neural marker for the amount of improvement that we see in the behaviour suggesting that neuroimaging might become part of a designed process for developing educational interventions. But we are also reminded of the many different components that are involved in reading and the importance of having multi-component interventions and the possibility of identifying individual differences in children's reading abilities that might help tailor those interventions to specific children.

Exercise, now I've already said that aerobic exercise is really important, and I think this is possibly one of the most undervalued and underrated pieces of knowledge that we have. There are many different attempts being made to improve executive function, but one thing that does seem to work is exercise. Schools often justify exercise because it's good for your health, it's good for team building, but actually you can justify it in terms of academic performance, because it improves your ability to think and when we look at differences in brain activities of people who are fit or unfit we see differences in the anterior cingulate, a very important part of the brain for paying attention.

You are likely to be paying attention more if you do regular exercise and in fact in this intervention here we can see when we compare physical exercise with listening to an audio book, these teenagers did 30 minutes a day and their response times are much faster after doing physical exercise. The executive function has improved.

We can also see well-established effects, for example, three minutes of intense running two bouts of three minutes of intense running can improve your memory for information you receive afterwards in the short, medium and the long term and those different types of memory are associated with different types of process in the brain and we have evidence for understanding and explaining how that comes about. Exercise is one of the issues with teenagers, but there are many other issues as well. We're beginning to understand that the teenage brain is not like a child's and it's not like an adult's – it actually has its own stage of development.

One of the things that occurs during adolescence is that there is a change in circadian rhythms and that means that there is some biological excuse for children wanting to stay up later and being more sleepy in the morning and not wanting to get out of bed, but of course it's not that simple because there are also a lot of changes in terms of the amount of freedom they have, they become much more interested in their friends and the opinions of their peers.

We certainly often have a sleep problem with teenagers and there are issues, there have been various attempts to try to remediate this and there are quite a few interventions in the UK going on now under the name of neuroscience and education that are funded by the Wellcome Trust, which is a neuroscience funder, and the Education Endowment Foundation which is an education funder and one of them is on sleep and so they are actually allowing a large number of teenagers to sleep in late before going to school to see if it improves their grades. They've tried this in America and they've shown that you get less sleepiness and you get better attendance. We're still waiting to see if it actually improves academic grades or not. We will have to see.

The two things that really contribute to a lack of sleep other than circadian rhythms that we know about with teenagers are technology and caffeine and quite often those are combined together and attempts to try to do something about that have included a more cultural approach, so for example getting the friends involved, getting the parents involved, conversations, phoning up home to make reminders, these sorts of things. When you just educate teenagers about sleep they learn an awful lot about sleep, but it appears they don't change their behaviour.

I should say the reason I've put this here is to remind me to say that sleep is not just about avoiding sleepiness the next day. If you lose sleep you will remember less about what you learn tomorrow because you'll be more tired, but you will also remember less about what you learned today if you miss your sleep tonight because during sleep you consolidate memory for the experiences you've had during the day so it's a double penalty. So sleep is really important for learning.

It's complicated though and I wanted to show you this study because it's a great study, but we could really do with more of them because it raises a lot of questions – 13 to 14 year olds between 6 and 7 o'clock were allowed to do one of three things – play computer games, watch TV or do nothing and then they were asked to do a type of homework where they had to remember some material and what we find is that slow wave sleep which is supposed to be the important type of sleep for consolidating memory is greatest for no technology, less for watching television and least for playing computer games, but notice this is between six and 7 o'clock, so if my children are only playing computer games between six and 7 o'clock, that's a good evening in my house, so I was quite shocked by this study. My worry is when they're playing computer games at 9 o'clock in the evening or 10 o'clock, but presumably that does much more damage. Their memory loss also corresponds to the amount of slow wave sleep that they lose, so least memory loss for their homework if they're not doing any technology, more memory loss if they're watching TV and most memory loss if they're playing computer games.

So all sorts of questions about this: what sort of computer game, does it make a difference? What would happen if they played it for a longer?

Involvement of sleep education interventions are beginning to show some promise, but really we need the engagement of social scientists in this because we need a cultural change. Now we are beginning to understand the neuroscience, the natural science, we need the social sciences involved to help us develop better interventions.

Spaced learning, where you space out your learning sessions is something we've known about for over 100 years from the psychologists, but it is being given new emphasis in neuroscience because we are beginning to understand what happens in the spaces when you space out learning and we can see activation in speech areas that suggests there is an internal dialogue going on probably to do with the learning in those spaces, so even though you're not conscious of it something is occurring which is causing you to rehearse what you have learnt and consolidate it in memory and there are many other things which I haven't got time to mention.

So many teachers are teaching children diagnosed with ADHD or are on psychoactive drugs, those teachers I think need to know about the brain basis about ADHD and what those psychoactive drugs are doing in order to better integrate and relate to children in that situation.

We know that when learners visualise something, in other words they imagine it, they're using almost as much visual cortex as they would if they were actually doing it, which gives you an indication of how powerful visualisation is as a potential learning tool.

Working memory training and brain training of executive function are really interesting areas. Adolescence I've mentioned, but there are many other aspects to it such as risk taking. Timing of education and much, much more. Too many things for me to put on here, but I did want to tell you about my particular interest which is games and reward.

The reason why I've focused on this area is because I'm aware that we have many children who are not behaviourally engaged in the classroom and we have an example here of a photograph of children that are not behaviourally engaged.

You imagine the teacher is standing over here, none of the eyes are facing forward and if the eyes are not facing forward, and it may be that they are discussing some educational concept or topic, but actually I happen to know they are not and if we don't have that behavioural engagement we know that is the biggest predictor, apart from socioeconomic status, that is the biggest predictor we have of educational outcome.

And yet we have a very poor understanding of how to use reward, we use rewards all the time in the classroom to try to improve behavioural engagement, but we have very little understanding of how they operate. I mean this is one of the most recent studies that was done, it was evaluated at the University of Bristol, where children were offered cash rewards for good examination grades and it had no effect on the GCSE grades at all, so if you're a parent maybe that's a good thing! Otherwise I'd feel a terrible obligation to offer my children lots of money.

But it also demonstrates that we don't really understand the relationship between offering rewards and getting academic results. But look at this lovely relationship. This is remembering information, so it's a type of learning but actually there's good evidence to think that it's not just about remembering facts. But learning increasing as this area of the brain, the ventral striatum increases its activity.

In other words, although there's a very poor relationship between the rewards we offer and the results we get, there's probably a very good relationship between the way in which the brain responds to the rewards and the results that we get.

So what we need to understand more about is the way in which the brain responds to rewards and there are ways that we know we can increase that, for example, when you're playing video games there are very big increases in that part of the brain, very big increases in activity.

And the sorts of increases in activity in the reward system that we see when people are playing video games it's comparable to taking methylphenidate or some amphetamine drugs and that may explain why and this is a very old statistic so forgive me, but I haven't got a more recent one, but back in 1998 one in five teenagers was potentially addicted to video games because they are so massively engaging.

Why are they massively engaging? Well one of the reasons may be that they offer a very rapid schedule of uncertain rewards, rewards that are mediated by chance and let me try to explain the significance of that.

This monkey has been trained to look at different visual patterns and we are measuring the dopamine uptake in the midbrain region. Some of these visual patterns it's seen before and some it's never seen before. If and sometimes when it sees a particular type of visual pattern it knows it's going to get a reward because it always received a reward when it saw that visual pattern in the past.

So that is one hundred percent, probability of one point zero, when it sees a reward that has always been, sorry, when it sees a pattern that has always been associated with a reward. When it sees that pattern it gets a spike of dopamine, but when the reward actually arrives, you can see that's the reward arriving there, there's no increase in dopamine because reward response is all based on expectations.

So it sees the pattern, as soon as it knows it's going to get the reward that's when you get the response, that's when you get the midbrain dopamine uptake, but you don't see it when the reward actually arises.

Now you take this pattern down here. This pattern is not associated with reward at all, so when it appears on the screen there's no spike of dopamine, but when a reward arrives unexpectedly you get that spike. "Oh yes I do want that thank you very much", because this signal is all about wanting something, it's not about pleasure, it's about wanting.

And the most interesting thing is when it sees a pattern that on half the occasions being associated with a reward and on half the occasions is not. Then, this is an uncertain reward. Then it gets a spike of dopamine as if it knows it's going to get the reward and then the dopamine ramps up until the outcome is known.

Now that means if you integrate over time, there is more midbrain dopamine for uncertain reward than either totally expected reward or totally unexpected reward. So uncertain rewards stimulate the reward system much more and yet we don't really do that in schools. Most the time we like children to know they're going to get a reward if they do the work.

So we tried this out in various different ways, offering uncertain rewards. Now what do I mean by that? I'll give you an example. If I give you a question, I could say if you get this correct you can have a point. But in these types of intervention I'm actually saying, no, if you get this correct we'll spin a wheel or we'll toss a coin and if it's heads you get two points and if it's tails you get no points at all. That appears to be more motivating than if I just offer you a point for a correct answer.

And we've actually been developing this approach with teachers. We've been testing it out. This is quite interesting because this is where we tested it out with adults and what we found was that not just seeing the coin being tossed gives the emotional response, but also the answering of the question.

There is a greater emotional response when you are answering the question in that context, in a gaming context with uncertain reward, than certain reward. In other words the uncertain reward transforms the emotional experience of tackling the academic task.

And we were worried about this because we thought the children were saying this is really unfair because suddenly a child's achievement in terms of the number of points is no longer completely predicted by whether they get correct answers or not and we thought they'd be saying, oh this is really unfair, but they didn't.

In fact, there were no questions about fairness. It was really about sport talk. So if the children were not doing very well, and remember you need learning and luck to do well, but if they were not doing very well they would say, well we're just really unlucky. But if they were doing well, then they would say that was absolutely brilliant! So they would take attribution when they had done well, but were able to dismiss the issue when they're done badly.

And that meant that they maintain their motivation throughout the lessons. We didn't know how you respond when you see somebody else get a reward. So we had to carry out a neuroimaging study to look at that and what we found was actually that you respond to your competitors' unexpected failure.

Now you might not think that that's particularly surprising, but it kind of conflicts with some of what we understood about neuroscience at the time. So it was a good thing to do the study. So whether it's you that's getting the unexpected rewards or somebody else that's getting unexpected rewards there is this increase in uptake of dopamine from the midbrain and this is actually implemented in an app that you can play on *Zondle*, which at the moment it's free, although I've got a horrible feeling they're going to start charging soon. But you can play this with your students and the students can respond using mobile phones and it allows the teacher to remain at the center of the classroom whilst all the children using laptops, iPods, or anything connected to the net are all responding together.

Now of course just that connectivity can be very helpful in terms of learning because all the children are getting feedback on their answers, but also they've got this uncertain reward which is making the whole experience a lot more emotional and it's being used in over twenty countries and there have been two other studies that looked at this uncertain reward effect and they've confirmed our findings.

We are now rolling this out to eighty schools, involving ten thousand children. Children will be experiencing a game-based approach for the whole of year eight. That's between the ages of twelve and thirteen years old, they're going to be learning science entirely through a game-based approach. So every lesson will involve questions for uncertain rewards and it will be interesting to see what happens.

This is almost the final slide. I just wanted to show you that we are still carrying on with the neuroimaging research and we've taken the conditions that we are looking at in schools, we're looking at the game-based condition for uncertain rewards. We're looking for a test-based condition using certain rewards and we're looking at just normal teaching.

And we've taken those sorts of conditions and we've been looking at them inside a brain scanner and what we found is that the more you gamify learning, the more you turn learning into a game, the more you get deactivation of this network. This network is the default mode network and it activates when you start thinking about yourself or when your mind is wandering. So if I'm not keeping your attention and you're thinking about what you might be doing later, your default mode network is activating. But if I'd been performing this lecture more as a game then that would have been less activated and your attention would have been more external.

And we actually found that the more our participants deactivated their default mode network, the more they learnt and there was much more deactivation in the gamified conditions, in the conditions that were a game and that is currently under review for a journal called *Frontiers in Psychology*.

Questions

How can we introduce neuroscience in the day-to-day activities in the classroom?

This is a huge issue because the language, concepts and the perspectives and the professional goals of neuroscientists and educators are very different. So that's why I wrote a book about it in a way and maybe I could have written that book more clearly now, because that was five years ago, but I still think that was me in a way trying to work through the issues that are involved.

I think we do need people who are trained in both areas, we need hybrid professionals, so we have started a master's in neuroscience and education, an MSc, at Bristol. There is also now one in London. But I also know that there are initiatives that are going on here in Barcelona which are very exciting and so locally there are attempts to bring neuroscience and education together and so I'm wondering if actually Diego should be telling you about those and encouraging neuroscientists and teachers to get involved with that network.

We have people who are making a lot of money out of brain-based ideas that are very loud and very present in the discourse, but actually it's where authentic neuroscientists are talking to teacher trainers and to teachers that we are getting a joint discourse that is meaningful.

So there are now some books that are available. For example, *Neuroscience and Education: The Good, The Bad and The Ugly*, which is a strange book. Strange title, but it's a good book, it has lots of good stuff in it. There's the book that I've written, there's a book by Sarah Blakemore and Uta Frith, *The Learning Brain,* which is very good and there are at least two journals. We have the *Journal for Mind, Brain and Education* from Wiley Online Education.

So we have some authorities in terms of places you can go to which are publishing and which are worth reading and we also have some networks internationally, *International Mind Brain Education Society* that publish. But also locally and I think the local is really, really important because actually educators need to make sure that their issues, the things that they are worried about, are becoming part of, are really central in the discourse, and those vary from one country to the next. So the message from neuroscience for education in South America, where this is also happening, is very different. There are very different needs and issues compared with Europe.

Should teachers be trained in neuroscience?

In terms of my approach, I believe we need to have multi-interdisciplinary research involving educators and neuroscientists all the way through from formulating the research question, to doing bridging studies, to formulating the question, scientific studies using FMRI or neuroimaging techniques that give us scientific insights that are closer to what educators need, the questions the educators have.

We need bridging studies to look at the meaning of those concepts in the classroom and then we need practice-based studies to develop better practice in the classroom and all of those require different types of technique, from natural science methods through to more experientially based action research type methods. Action research, neuroscientists haven't got a clue what action research is, but it's very, very important in education for developing good practice and we need to combine all those together.

And even at that stage it's important to have the neuroscience involved because you will be generating the concepts to communicate and transfer what happens in the classroom to other teachers and it's important that there is a monitoring of that to make sure the concepts don't come off the rails and I've been able to do that to some extent with creativity, which I haven't been able to talk about because we haven't got time. To a greater extent with game-based learning just really as a model, well that was one of the reasons why I did it, to show that it could be done. We've got all of those studies in there.

It's a long process it's not a short journey, it's a long journey, but that's really what we need. However there are still some immediate things that we can do and one of them is to get rid of the neuro-myths. So as well as some interventions that can be used in the classroom now and game-based learning, I think, is one of them. There is also this issue of getting rid of neuro-myths. And those things can happen right now.

What role does technology play in the application of neuroscience in learning?

My intervention very much uses technology. In fact we introduce it to schools as a technology-based intervention. I think because technology is moving very quickly and neuroscience is moving very quickly, my feeling is that it's going to be technology-based interventions that take off first in this area. Because of the culture of technology and the culture of neuroscience I think they are more easily combined and also because much of what we know from the neuroscience is done using technological platforms. So in a way it's easier to transfer the concepts.

The Flipped Classroom

The Flipped classroom. So I think there has to come a time when people say – it's really important people say they don't know sometimes and I don't know whether the flipped classroom works or not. I don't know what the neuroscience would be in that situation and I can't really comment, to be honest with you. It's very popular in the UK too, but I honestly do not know whether it works and I don't know how our understanding of brain function would feed into our understanding of the flipped classroom at the moment. So I actually have to put my hands up and say I don't know on that one.

Is there a scientific basis for thinking that learning styles lead to better results?

Learning styles is a real worry because, you know, my statements about learning styles are based on readings of the literature, but also on other experts' readings of the literature and at the moment there really just is not the educational evidence to show that it is worthwhile identifying somebody's learning style using any technique that has so far been created. I would love to see that evidence. There may be one or two studies showing some effects, but in terms of there being a consistent approach that works, the evidence is just not there.

That is not to say that you should not differentiate, it is important to differentiate in the classroom, but I would rather see a teacher understanding their student in a much broader way using a more commonsense approach in terms of the student's ability, their perceived personality, their interests, for example. So it's really important for teachers to change their teaching approach based on how they understand their learner. I mean that's really Vygotsky, understanding where somebody is and then building them up and taking them further.

My problem with learning styles is that the instruments that are used just do not identify meaningful enough categories of learners. So if you find some evidence please send it to me. But at the moment I just cannot see the evidence in the literature and it's not just me. There are other scientists who have looked at this and come to exactly the same conclusions.

In the UK, The Department for Education until 2007 was recommending the use of learning styles, visual, auditory, kinesthetic, on its website, The Department for Education and they noticed in 2005 that they had no evidence to support that recommendation and it took them two years to find a way of politically disengaging without too much embarrassment.

That disengagement has now been made, but it's true that around the world teachers and governments have accepted this because it's easy. It seems to make sense, you sort of think, well if I know something about the learner and I know what they prefer and I teach that preference, it should make a difference. But there's not the evidence. So I'm sorry, but

I would robustly stick to my position on that, but I'm interested always to look at other evidence, if there's new evidence.

Can neuroscience be applied better to some subjects than others?

Our preliminary research and actually developing the gaming was based on a more action research approach whereby we were working with quite small classes and just trying to change things to understand how it operated and in those days we were going from one subject to the next.

We actually started with literacy with a special needs group with low ability literacy, thirteen, fourteen year olds, but then moved on to history. I worked using it in design and technology and really anything, I think you can just about use any topic with it in terms of the principles that are involved.

I think a question that is often raised, which kind of relates to your question actually, is, is this just for facts? You know, I mean if you're working with history, dates, then it's obvious how you can use it because you just have to remember the dates, but it should operate in other ways. So you're not just learning but you're also improving understanding, but that depends on the design of the questions.

So people think multiple-choice questions are just about facts. They're just at one level of Bloom's Taxonomy and so in the FMRI study we did we made sure that we hit all of Bloom's levels of knowledge and understanding except creativity, which was too complicated for us to assess and therefore it's important not to think that this is restricted to facts, but also to appreciate that the effectiveness of the approach depends on your ability to design really good questions that probe deep understanding not just recall of knowledge.

We've chosen science for this massive intervention because that's the one that you know is probably going to produce the most interesting results. It's been tested by a Turkish group in published research in *Database Knowledge*, knowledge of databases from an undergraduate software course or something. I think the Devonshire paper tested the approach using sex education, I think it was.

We've chosen science because there's such a nice range of different levels of understanding that you can easily generate and test, but it should be appropriate for all subjects really, but it depends on the skill of the question designer. So in our project we are also now spending a lot of time designing questions, because that is absolutely key.

What features must a video game have to be educational?

It's not just uncertain reward, there are many other characteristics that are likely to be important. So there is a competitive nature to it and there is also the fact that rewards are often escalating. Another theory that we're looking at is the role of action, which actually relates to the question from online, about using the body more to learn better. Because when you're producing very rapid actions, especially cue directed actions, you produce another neurotransmitter called acetylcholine, which can be related to improved memory and learning. So it may be competitiveness, uncertain reward, the rapid schedule of rewards, the escalation of rewards and action is also likely to be an issue as well. So we are trying to unpick those.

In the intervention that we did with the FMRI study we only had three factors: competition, uncertain rewards and escalation of rewards, but those seem to be sufficient enough to improve learning.

In terms of quizzes and learning how can we be sure they're actually doing anything in educational terms? Well when we first started applying this research we had a year eight science class and we did a reproduction and we had a great big wheel of fortune that we were using and we were giving out plastic tokens using uncertain reward and we had fantastic engagement.

And we tested – pretest and post test – and that's a really important thing to do to see what the children actually learn during the lesson. Don't leave it to chance, find out. And we were able to show that they learned absolutely nothing at all. So there is a really important point here. Because you can't go straight from brain scan to lesson plan. You need to work with teachers and combine what you know about how the brain learns with what teachers understand about how children learn and combine those two things together.

I remember the head teacher standing at the back of the class saying actually this is just like a Christmas quiz, and we were thinking, yeah it is like a Christmas quiz and are these children learning? We looked at the paper. No, they're not learning at all.

What we needed to understand was that we had to exploit that window of excitement. So there is a stage during the game, that's built into the game, so you know when they have answered the question, when they've made their decision whether to game and they're waiting for that wheel to spin, they're waiting to find out if they have the answer correct as well, that's when their dopamine is ramping up and that is a teachable moment and so we encourage our teachers to focus and use that as a teachable moment and as soon as we started doing that then we saw the improvements in learning that we were looking for.

So what we now encourage is not just use it as a quiz in fact we tell them don't use it as a quiz, it's not a quiz. It should be part of the lesson and when you present it, when the children are answering and when you're giving feedback use it as an opportunity to scaffold the learning. Remind the children the principals, sometimes to differentiate and give some extra support when needed and basically have it built in to the learning. Otherwise my guess is that it won't work.

What needs to be done for play to have an impact on learning?

You don't want bells and buttons and wizzes and wooshes distracting children from the learning. You've got to design not only the game, the technology, but also the pedagogical approach to keep the children focused on the learning. And it certainly is a reworking of teachers' expertise and what they understand about learning. That is the name of the game. It is not about providing...neuroscience is not going to provide a simple technological solution that replaces any of that. In fact it's going to make it more difficult, I can promise you. Yeah, but it's worth doing, I feel, but there's no shortcuts in this at all.

And it's very difficult because we're putting in a lot of time and effort into working with teachers to try to develop ways of transferring this expertise as quickly as possible, but we know teachers have very, very little time to do it. So we're coming down to using sort of twenty second videos, just twenty second videos though, because they haven't got time to sit there for thirty minutes. And that is a big part of the challenge.

How can we improve social learning through neuroscience?

I think the important thing that neuroscience can contribute is a greater awareness of the significance of emotions in the classroom. That's really important. Social learning, interestingly because of the rise of social cognitive neuroscience, we have a better understanding of the reward response that you feel and the brain's reward system around agency, taking a choice, other people's company, sharing attention is a really important thing that we are gaining insight into.

The difference between attention and engagement is that attention may orientate children towards the board, but it's not what we're talking about which is encouraging that deeper processing and scaffolding the children's learning. That has to come from the expertise that we've already developed within education that the teachers hold and that's where the expertise of teachers needs to feed in to this new venture.

Embodied commission. Fascinating area, I think. Mirror neurons are likely to play a role in our understanding of that, although there's been a lot of hot air about the mirror neurons, actually, whether they are learnt or whether they are not learnt the way in which you respond to another person's movement seems very significant in understanding their communication and I'm aware that I'm doing that now.

About the author

After completing a PhD in Medical Physics, Professor Howard-Jones was a teacher and a trainer of primary and secondary school teachers, before becoming a psychologist. This experience promoted his interest in applying understanding of cognition and neuroscience to enhance child and adult learning.

In particular in recent years, he has been conducting experiments to help find more information on how to foster creativity in the classroom through the use of new technologies.

His research combines neurocomputational modelling with functional brain imaging to further understand the relationship between reward and learning. The methods used for this modelling focus on producing educational learning games.

As a member of the UK's Royal Society working group on Neuroscience and Education, he took part in preparing a report on the implications of neuroscience in education in 2011 (link). Some of its conclusions were:

- Learning outcomes are not solely determined by the environment. Biological factors also play an important role.
- Neuroscience can help uncover why certain types of learning are more rewarding than others.
- Learning new skills changes the brain and these changes revert when practice of the skill ceases. Hence "use it or lose it" is an important principle for lifelong learning.
- Resilience to stress and adversity can be built up through education with lifelong effects into old age.
- Digital technologies have the potential to create more learning opportunities inside and outside the classroom, and throughout life.

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