Chapter 3
Brain Research and Learning over the Life Cycle

by
Manfred Spitzer*

Spitzer's argument is that brain research not only shows that we are born for learning and do it for our entire life, but also shows the conditions for successful learning and differences in learning at different stages of life. The time has come, he says, to use this understanding for shaping the learning environments and learning programmes; we can no longer afford to treat the most important resource that we have, our brain, as if we knew nothing about how it works. Thus, it is important to create the conditions for transferring insights from basic studies of learning in brain research to the practice of teaching. His discussion is organised around the following themes: from examples to rules; mechanisms for learning; phases, stages and windows; schooling and learning for life; emotions and learning; the decreasing rate of learning with age; learning, age and wisdom.

Since the times of reflex physiology, in the first decades of the last century, learning has been the quintessential subject of brain research. This chapter will show that brain research is a necessary foundation for understanding learning processes, including ways that schooling could be more effectively personalised. We are able to learn for our entire lifetime, and indeed are required to do so, so I will draw on examples from the entire human lifespan.

Some readers might consider the connection between the two main terms of the title, namely brain research and learning, a bridge too far. They might argue that brain research is still in its infancy, is about abstract domains, such as single cells, synapses, transmitters, receptors and ion currents and thus much too removed from the classroom. This is not the case

* Medical Director, Professor and Chairman of the Psychiatric Hospital at the University of Ulm, Germany.

and there is an urgent need to include the findings of brain research in profound reflections about shaping *learning environments* – a term I use for everything that has to do with learning – from different school types and curricula, to classrooms, to the relationship between learner and teacher.

The brain is always learning

Most people associate learning with school, with memorising and cramming, with sweat and frustration, bad grades and exhausting examinations; let's face it, learning has a negative image. It is considered unpleasant and people feel the need to reward themselves for learning ("one piece of chocolate for every word of French vocabulary"). It is a pity that learning theory, deriving from psychology in the middle of the last century, also comes with this view, and this has an important consequence. For, on this view there is no learning during leisure time; learning is work and as such is separated from leisure activities. Furthermore, in our culture as students we separate the day into time which we unfortunately have to spend in school (university, professional school, further education, etc.), and leisure time during which we are free and do not have to learn anything.

This view, however, does not correspond to the nature of learning. As the wings of the albatross and the fins of the whale are optimally adapted to the characteristics of air and water, like density or viscosity, our brain is optimally adapted to learning. Therefore, our brain does not learn somehow and incidentally, more or less well, or only when it has to do so. From an evolutionary perspective, the human brain has evolved to do nothing else better than learning and to prefer nothing else to it! In fact, the brain is always learning, whenever it processes information. The sceptical teacher may interrupt: "the brain is always learning and has fun with it. What an outlandish theory! I see 25 counterexamples every morning when I enter my classroom!" That someone might say this only proves my case, *i.e.*, how much we have neglected, and still neglect, the scientific insights of brain research in the realm of schools.

From examples to rules

Humans are born to learn: all babies are a living proof of that. They are the best at learning, are made for learning, and cannot be stopped. Two-year-olds do not behave like reflex robots or containers to be filled with facts. Instead, they actively try to understand their environment by examining it with little tests – quite similar to scientists – and proofing hypotheses about how things really are. Three-year-olds learn a new word every 90 minutes, and at the age of five, children know not only thousands of words in their mother tongue, but also the use of their language and its complicated grammar.

At kindergarten-age, German children know for example that verbs with the ending "–ieren" form the past tense without the prefix "ge-". Thus when they use the past tense of the verb "spazieren", (to "stroll" in English), they say: "wir sind spaziert" ("we strolled") instead of "wir sind ge-spaziert". In contrast, when they want to say that they walked ("to walk"= "laufen" in German), they say "wir sind gelaufen", knowing that they have to build the past tense of the verb "laufen" with the prefix "ge-". One could argue that the children had picked up the participles as well as the infinitive forms of the verbs, and thus learned them by heart. But this is not the case, as a simple experiment can show. We tell the children a story using some verbs that do not exist in German, and afterwards ask them about the story and find out how they build the past tense of these verbs. For example, we could tell a story about dwarfs who "quangen" and "patieren". If we ask them what the dwarfs did, they say that the dwarf "sind gequangt" and "sind patiert" (without "ge-"). That children are able to juggle grammatically with words which do not exist is proof that they learned a rule, and didn't merely memorise thousands of examples. But no one taught this rule to the children: *they generated it by themselves.* Brains have the ability to generate rules from examples. All that is needed, therefore, are the right examples – lots and lots of them.

To use an English example, when children learn the past tense, they start with frequent words they hear a lot, and thereby learn single examples: be/was/were, have/had, go/went, etc. After a while, the language production parts of their brain have done more than rote memorisation, so the children will use the ending -ed to form the past tense of words, even if they have never heard the words before. But they may also say something like "haved" or even "wented", even though they have never heard this before. So they have, without any explicit knowledge about it, found out about the rule and used it.

After language acquisition, learning really gets off the ground: school, apprenticeship, university, lifelong further education, maybe from time to time a new activity field, a foreign language, a new hobby, or simply a new environment, spatially or socially. We are constantly learning, throughout our entire life. Consequently, brain research shows that the principle – "the brain by itself constructs rules based on examples" – is valid for the entire lifespan, even if it must be supplemented by further rules.

Our brain is always learning. It weighs about 1.4 kg, which is only about 2% of the body weight. However, it uses more than 20% of the energy that we supply with food. Thereby, it not only processes information day and night, but also chooses which information is worth storing, in order to be better prepared for reaction and action in the outside world in the future. Nerve cells differ from other types of cells of the skin, muscle, or glands in that they *represent* something. I do not mean "representation" metaphorically but instead literally as an account of what a neuron is doing. A neuron is active exactly when a certain input is present, like touching a body part, hearing a word, or recognising a location. Information is processed within the nervous system in the form of action potentials, which have no qualities other than being present or absent. These signals do not smell and they have no colour; they are not even small or big. Neurons receive signals either from the sensory organs – analog-digital transducers that produce output signals from the input of physical characteristics of the environment – or from other neurons.

At synapses incoming electrical signals are chemically transferred to the receiving neuron. The point of synapses is that they are of different strength, *i.e.*, neurons receive signals via stronger or weaker connections. Depending on the strength of the transmission, the same input signal can activate one neuron but not another.

The human brain contains in the order of 100 billion (10^{11}) neurons and each neuron has up to 10 thousand connections, of which less than ten are to the same neuron, such that each neuron is connected with a thousand other neurons. So there are, approximately, 100 trillion connections (10^{14}). As neurons work by representing something, and as this means that there must be 10^{14} finely-tuned synapses in our brains, the question arises of how this is achieved. The answer is simple: Everybody does it by him- or herself! From a neurobiological point of view, all learning occurs via changes in the strength of such neuronal connections at synapses. As synapses change when they transmit signals, learning occurs whenever the brain processes information. Thus, learning is not a process that the brain needs to manage *in addition to* perception, thinking and feeling, but instead occurs automatically whenever the brain is perceiving, thinking or feeling.

Mechanisms for learning individual items and general patterns

We are able to learn single facts as well as the general rules and connections: we learn words as well as grammar, individual places as well as geometry. We learn to know individual people and general psychology. When we learn single items (people, places, words, events), the hippocampus is the part of the brain which is the most important for this type of learning, in contrast with the cortex which is engaged in extracting rules. The hippocampus is a small structure that lies deep in the temporal lobe.

Neurons in the hippocampus can be directly observed when learning new contents. When a rodent learns to find its way around an unfamiliar environment, new representations of that environment are created in the hippocampus. In humans, learning vocabulary – similar to learning new environments in rodents – depends on the creation of representations in the hippocampus. The hippocampus learns important and new details quickly. 11 September 2001 will stay in the memory of most of us quite well, when two airplanes hijacked by terrorists crashed into the two towers of the World Trade Center in New York City. Where were you when you first heard about it? Who was with you? With whom did you talk about it for the first time? Most people are able to answer these questions easily, but can't remember the afternoon of the most recent September 11 – even though it happened much closer to the present. The hippocampus stores details only when they fulfil two qualities: novelty and significance. We only have to hear important news once to remember it.

In contrast with the hippocampus, the cortex is more like a "rule-extraction-machine". The synaptic connections between its neurons only change a tiny bit during a learning episode. That is why we are unable to remember most of our impressions later on. The fact that our brain does not record events as a video-recorder would, but rather extracts the rules underlying the events, is advantageous for several reasons. First, less storage capacity is needed if just the rules are stored and not every single event. Secondly, past coincidences are not useful for the guidance of future behaviour but past rules are. By definition, coincidences will be different tomorrow from what they have been today so they are of no help in the future. And so the brain would waste resources if it stored them.

Take an example: you probably have already eaten or seen thousands of tomatoes during your lifetime, but you are unable to remember every single tomato. Why should you? Then your brain would be full of tomatoes! And these would be totally useless, when you come across the next tomato. Only your *general* knowledge about tomatoes is useful in order to deal adequately with this tomato. Tomatoes are edible, they taste good, they can be processed into ketchup, and so forth – you know all of this because you have already come across a lot of tomatoes, of which you remember only the general and structural characteristics.

Therefore, in many cases the learning of single facts or events is not only unnecessary, but also unfavourable. With the exception of places, people, and important events of personal life, the knowledge of details is otherwise not very helpful. Fortunately, we do not learn every single detail. On the contrary, our brain – except for the hippocampus, which is specialised in details – is interested in learning general rules and categories, and this not by *memorising* them but by the processing of examples and extracting generalities. This is what the brain is doing anyway because this is what we need to do to survive. When something learned in school can be applied later in life, it is mostly of this general structure – it is a rule, a general connection, acquired and strengthened by usage through many examples. Just because it is general, it not only concerns the examples, but can also be applied to new matters. This is in strong contrast to learning single facts, such as the highest mountain of Greenland, the Gross National Product of Nigeria, the birth date of Mozart, or the citric acid cycle. Such facts are useless for the everyday problems of life.

This idea is stressed in recent discussions when it is proposed we should teach "competencies", "cultural techniques" and "problem-solving strategies" instead of facts. But it is important to keep in mind that the general is learned by examples, and not through the learning of rules. Hence, practising with many examples should be an important part of every school day. Or, expressed the other way round, if facts cannot be used as examples for a more general context, it is better to do without them.

Phases, stages, and windows

Some things can be learned at different times during the lifetime of the learning organism. In ducks, imprinting happens after birth; in songbirds, singing is learned around puberty; and in nut-storing birds, the storage techniques are learned during childhood. As human beings have a long developmental period until they reach adulthood, we may infer that there are quite a number of phases, or stages of learning, or critical periods, or windows of opportunity.

And this is in fact what we do find in real people. There are different learning phases during the lifespan of a person, and they exist for different reasons. First, the brain of the newborn is still quite immature, *i.e.* it develops while it learns. This means, secondly, that early learning is especially meaningful. Third, the rate of learning decreases with increasing age. And fourth, the one who already knows something learns differently from the one who starts from the beginning. The brain of a newborn contains practically all neurons, but many of them are not yet or only slightly linked. As all learning consists of a change in the connections between neurons, this has important consequences, which are being looked at only recently in the field of cognitive developmental neurobiology. Let us look at some examples.

The environment of a newborn is very complex. When it learns something, it would make sense if it learned simple matters first and more and more complex ones afterwards. Learning complexity is based upon already-learned simplicity. How can the baby learn anything under these circumstances? The answer from cognitive neuroscience is astonishing: the newborn learns so well precisely because its brain is still immature. At first, its brain works in the simplest manner and hence is only able to process the simplest rules. And thus, it is only able to learn these. Once they are learned, other mechanisms take care that what has been learned will not then be forgotten. At the same time the brain develops, *i.e.* new connections are created which allow the processing of more complex contexts. Those are added to the very simple things and so on. Thus, the newborn does not need a teacher who prepares learning materials didactically, because its brain is still developing. Consider language development – if we had had our adult brain already at birth, we would have been unable to learn something as complex as language. And, the time window of language acquisition appears to close at around age 12 or 13, so that if someone has not learned how to talk by then, they never will.

We know that the representations – the neurons that code for something particular – are not just distributed randomly in the brain. The cortex by itself has the ability to create *maps* of representations. We speak of a “map” because neurons, which represent something similar, are located closely together and that events that occur often are represented by more neurons than events that occur rarely. The development of these “maps” depends on experience so that what is experienced will be represented. The best-known map is the sensory cortex, the part of the cortex which is important for the processing of touch signals coming from the body surface. As we process more touch information with our hands, lips and tongue, these body parts are represented by more neurons in the somato-sensory cortex than body parts with which we rarely process important touch information, like the back. The map, in a way, contains the statistics of the information of touch coming in. We now know that there are many maps in the cortex that are not only relevant for touch information, but also for seeing and hearing and probably also for higher cognitive functions like language, thinking, and wanting.

Furthermore, new research has demonstrated that the experience-based development of the maps is the signal for their consolidation (Chang and Merzenich, 2003). In other words, as long as no map is created, the corresponding part of the brain stays flexible. But once a map has been created based on the processing of the corresponding experiences then the consolidation cannot be, or only slightly, changed again. This explains the special importance of early experiences. It also determines how much capacity for processing (*i.e.* cortical hardware) is created for certain representations. If someone did not use her or his hands for the first three years of life, he or she would be able to use them to touch later, but the touch would not be as precise as it could have been. On the other hand, if someone learns to play guitar as a child, touching often very precisely with the fingers of the left hand, (s)he will have a few centimetres more for the representation of his(her) left hand in his(her) adult brain (Elbert *et al.* 1995).

The developing brain is the cause for the existence of learning phases, stages, periods, or windows. We still know relatively little but we do have a field – developmental cognitive neuroscience – devoted to it. Its results should be of great importance for shaping the learning environment.

Schooling and learning for life

We do not learn for the school, but for life. This educational principle is more important today than ever. In schools 150 years ago, students already learned for their lives. But at that time, it was known more or less what life looked like and which knowledge was to be used. One hundred years ago, there was considerable certainty about what students should learn – their mother tongue, mathematics, physics, chemistry, languages, etc. Now we know that the world looked very different only 30 years later. Not only were there cars, planes, radios and telegraphs, but also eugenics, new kinds of poverty, unemployment, social problems, recession and new global policies. A person in 1900, who thought that he/she knew what students should learn to be fit for life, was mistaken.

Nowadays we are smarter in one respect – we know that we do not know what life will be like in 30 years time. By implication we do not know if something which is learned in school today will be useful then. And progress appears, if anything, to happen at an ever faster pace. Hence, the above-mentioned principle has become *more important and at the same time more uncertain* than ever. How can we make sure that material is really learned for life? With this in mind, people often reason as follows: because of rapid change and the accompanying uncertainties, the learning of facts in school is becoming obsolete. Rather, problem-solving strategies are important – the knowledge of general rules and skills, not details and facts, which can be applied to different problems, even those unknown today. These skills should be so general and basic, that people speak of the acquisition of "meta-cognitive basic competencies" and the like.

This sounds plausible but on closer scrutiny it turns out to be too general and shallow. Neuro-scientific studies of the mechanisms of learning in human beings allow for more precise analysis of how to connect schooling and learning. For instance, we now have insights on how to improve the prospects that what is learned in school will result in long-lasting skills that can be applied to practice-orientated problem solving throughout life.

Emotions and learning

A recent study (Erk *et al.*, 2003) of the role of emotions in learning has shown for the first time that *neutral* material is stored in different parts of the brain, depending on the emotional state of the learner when the material was learned. This study examined brain activity with functional magnetic resonance imaging (fMRI) during the encoding of words. We wanted to find out if memory performance for neutral words differed for learning in a positive, neutral or negative emotional state, and if different brain regions are involved for each case. In order to do so, we set up an experiment, consisting of many trials that were carried out in the scanner. In each trial, subjects were first presented with a picture, which conjured up positive, negative or neutral emotions. Then a neutral word was presented, and the subject's task was to indicate, by pressing one of two buttons, whether the word denoted something abstract or concrete. This decision process ensured that subjects actually paid attention to the words and processed their meaning. This series of presentation was repeated many times while subjects lay in the magnetic resonance tomograph. Afterwards they were asked to freely recall the words, and to write them down.

The results were stunning. First, we could demonstrate that the emotional context in which word storage happened does influence subsequent memory performance. Words that were stored in a positive emotional context were remembered the best. Moreover, we were also able to show that activity in various brain regions allowed us to predict whether or not a word would be remembered, depending on the emotional context under which the words were learned. Storing words embedded in a positive emotional context caused activity in the hippocampus and the para-hippocampus, *i.e.*, in areas related to learning and memory. In contrast, when words were encoded under a negative emotional context, the amygdala was active.

What does this mean for learning in schools? The hippocampus mediates learning of events. We know that events do not reside in the hippocampus for ever, but rather get transferred to the cortex within the ensuing days (in mice), weeks (in rats) and months (in human beings). In other words, the learned material is transferred from the fast-learning hippocampus to the "slower learner," the cortex, the brain's long-term storage device. The function of the amygdala is totally different. It contributes to fast learning and the future avoidance of unpleasant events. If the amygdala is destroyed in a rat on both sides of the brain, the rat can still learn to orientate in a maze using the hippocampus, but does not learn fear. In order to learn fear, humans as well as rats need the amygdala.

When the amygdala is activated, heart rate and blood pressure rise and the muscles contract: we are afraid and are prepared for fight or flight – a useful response in regard to imminent danger. However, the effects not only concern the body, but also the mind. When the lion comes from the left, we run to the right. The individual, who leans back and starts thinking laterally and creatively, does not live long. Fear produces a certain cognitive style that facilitates the execution of simple learned routines but at the same time, it blocks creativity. This made sense 100 000 years ago, but nowadays it often leads to problems. For someone with anxiety during an exam, it may be impossible to find a creative solution that would be easily identified when not in an anxious emotional state. Someone who is anxious will easily find him or herself "stuck" in a situation and incapable of "freeing the mind". When there is no anxiety, thoughts become more open, associations run freely, and new solutions to old problems pop into our minds. This fits with the subjective experience of most people and has also been demonstrated scientifically.

As the amygdala has the function to prepare us for fight and flight, its activation leads to mental changes that do not foster creative problem-solving. This means that if we want our children to learn for life in school, we need to make sure that the emotional atmosphere is right during learning. Our results not only show that learning works best in a pleasant atmosphere, but also why learning should only occur in a pleasant atmosphere. Personalisation, as is discussed elsewhere in this volume, may be one avenue for creating such positive learning contexts, particularly in light of the changes taking place in what people need to learn.

The decreasing rate of learning with age

"What little Hans has not learned, big Hans will never learn" is a German saying. And from many studies we know that indeed with increasing age, there is a decrease in the speed of learning processes and of its neuronal correlate, neuro-plasticity. Upon closer consideration, the decreasing learning rate with increasing age makes a lot of sense. All learning is a result of the change in the strength of synaptic transmission. In neural network models of learning, the amount of change in synaptic strength per single experience is expressed by a number, a so-called *learning constant*. A small learning constant, implementing learning in small steps, assures that things are not forgotten. Moreover, it avoids learning too quickly and thereby over-shooting the goal (*i.e.*, the true value of whatever has to be learned). So, in order to learn something precisely, learning has to be slow. Finally, learning in small steps makes sure that every single experience contributes only to a small extent to whatever is learned, such that the *general structures* of these experiences are learned through many repetitions, rather than single coincidental (and useless) features.

Such slow learning, however, contradicts the general demand for fast learning as dictated by evolution. The reason why learning should occur quickly is clear for every organism, so far as accessing nutritional resources or life-saving reactions in dangerous situations are concerned. Thus, organisms should learn slowly, in order to not forget and to generalise and to be precise, and quickly in order not to starve or be eaten up while still learning.

This contradiction is solved in living systems (as well as in artificial neural networks and in robotics) through initial fast learning followed by ever slower learning. Hence, the rate of learning must decline with increasing age for learning to occur optimally. The reason why children are fast learners and older people are slow learners is quite simple. For organisms to survive better in their environment, they need to get to know it better, so it is good to learn quickly first and then more slowly. This enables organisms to better estimate the true parameters of the environment in a short time, and then later get closer and closer to the true parameters. Transferred to humans, this implies that elderly people know many things much better than youngsters. It is not a coincidence that we speak of "old masters" with respect to people who have acquired knowledge over a lifetime.

The idea of a declining learning rate with age presupposes that learning occurs in a stable environment. However, given that our environment changes so quickly, the prerequisite of a stable environment is not any more given in many fields. Thus it is possible that people find themselves in a situation where the values, which they filtered out from their environment, are not valid any more, or that they learned skills, which are of no more use. The old master of building violins will be very good at that task but has great difficulty learning how to build synthesizers.

There are, however, fields, which basically do not change – mothers love their children, husbands their wives, grandparents their grandchildren, etc. – and some aspects of our social life are culturally quite stable through time and space. In contrast, science and technology are full of sweeping changes. Therefore, we should expect that it is at different points of the human life-span when someone is able to make contributions to these fields. And indeed, fundamental discoveries in mathematics and physics are made by young people: a 20-year-old mathematician, for example, invented group theory in a single night; physics in the 1920s was also known as the physics of the "twenties" (Heidenberg, Pauli, Schrödinger and the like), because at that time, young people caused our world-view to totter and changed our understanding of things. Fast learning, novelty-seeking, a fast Central Processing Unit, and lots of empty RAM, but no necessity of having loads of data stored on the hard drive (to use computing metaphors), is what it takes to be excel in maths and physics.

Learning, age and wisdom

It is quite different in the social sciences where great achievements are not made by 20-year-olds but by those in their 50s and 60s. It is not difficult to guess why this is the case for we are always learning in the field of social interaction. People – in contrast to the technical things that surround us – do not change so quickly. Accordingly, we learn to understand them better and better and become wiser in dealing with them. Theories in the social sciences and reflections on ethics and political issues are therefore rather the domain of older people. This does not mean that young people cannot, or should not, think about these things. But older people are in a better position than younger ones to assess socio-political problems. It makes sense that most constitutions provide people with the right to vote for president before they have the right to become president; people who are awarded the Nobel Peace Prize are much older at the time of their achievements than physicists at the time of theirs.

Older people learn more slowly than youngsters, but in contrast they have already learned a great deal and are able to use their acquired knowledge for the integration of new knowledge. The more one knows, the better one is able to link new concepts with already established knowledge. Since learning consists of the creation of such links, older people indeed have an advantage. Knowledge can help to structure new knowledge, to order and anchor it.

But knowledge can also make us blind to the things that are in front of our eyes. For older people, it is therefore important to stay open minded and to use the knowledge that they have already acquired for future learning. Older people do not learn facts as easily as younger people; they need anchoring points. And those points must fit their experiences. This is not easy to realise, as the practice in many companies shows when they try to teach new things to their employees the same way for everybody. No wonder this works the best with young employees and the worst with older ones. This is often used as an argument in favour of youth, but by not starting the teaching for older employees with what they already know, a lot of useful knowledge is not exploited. This knowledge can be important whenever a new problem has to be solved creatively. So, the question of who is better at learning, the younger or the older person, cannot be generally answered.

That learning at an older age is not a recent phenomenon linked to the inverted population pyramid may be illustrated by the following two examples. Walker and co-workers investigated the Arche tribe in Eastern Paraguay. The male Arche leave their settlements for a few days in order to hunt with other members of the tribe in the woods. They only use their hands, machetes, bows and arrows, with no guns or other modern weapons. At the age of 24 years, the people of this tribe reach their best physical fitness. How old are the ones who bring back home most of the meat? Since the beginning of the 1980s, researchers took notes on which member of the tribe killed what prey. As a result, a clear dependence of the success in hunting and age was found – the men who brought home the most prey were about 40 years old. Competitions in archery showed the same age dependency as the success in hunting. The number of hits increased until the age of about 40 and then stayed constant for the subsequent two decades. The same result was found for recognition of tracks. But in trying to teach archery – in a six-week crash course – to the members of the tribe that did not go hunting any more, they had not the slightest success.

It became clear that with hunting as with playing soccer, violin, or chess, performance is best after practising for at least two decades. If lifelong learning is so important for people who live under Stone Age-like circumstances, what about in today's society based upon knowledge and information? We tend to lay off the 50-year-old and employ the 24-year-old. This would have been a mistake even in the Stone Age! In today's society, which is based on knowledge and skills, this can only be extremely short-sighted.

A second example is about grandmothers not grandfathers. London-based anthropologists (Sear, Mace and McGregor, 2000) found in a study carried out in Gambia that the presence of the grandmother in a family led to the doubling of infant survival to adulthood, and another study demonstrated grandmother-dependent increases in fertility (Sear, Mace and McGregor, 2003). Data from Finland and Canada and on the survival of human beings over generations, taken from old records in the 18th and 19th century, lead to the same conclusion (Lahdenperä *et al.*, 2004). Even studies in elephants and apes point in the same direction. In elephants, the age of the matriarch (the oldest female in a group of ten to a dozen females) is highly correlated with the fertility of the younger members of the group (McComb *et al.*, 2001), while the grandmother making sure that the mother takes care of her new baby has been observed in gorillas (Nakamichi *et al.*, 2004). These studies clarify the value of old age for species that live in groups. When there are no written records, let alone the Internet, then older individuals are the only source of information and experience which is healthy for the reproductive success of the entire group.

Summing up and based on characteristics in information-processing at different stages of life, it is an advantage when people of different ages live and work together. The older person has a larger and more profound basis of knowledge, the younger person has a better working memory and faster processing speed. If a problem is intensely studied by such a community, the probability of a solution is maximal. Observations from the field of anthropology show that even simple cultures appreciate life experience. The challenge for our society is the transfer of these facts into our everyday life. If aging is seen as an annoying problem of a population pyramid that stands on its head, this possibility has already been lost. Older people should not only be conscious of their value but also of their function. They surely will not fulfil their value and function just by playing golf or cards!

Conclusion

Brain research not only shows that we are born for learning and do it for our entire life. It also shows the conditions for successful learning and differences in learning at different stages of life. The time has come for us to use this understanding for shaping the learning environments and learning programmes. We can no longer afford to treat the most important resource that we have, our brain, as if we knew nothing about how it works. Brain research is still in its early stages and we know relatively little, but the little we know is important for improving learning processes.

Medicine offers one model of how the application of basic science to practical use can be made a reality. Today's discussion about the funding of medical treatment is possibly the best indicator for its success: everyone wants medical treatment of the highest level. Medicine reached this point as it moved from anecdotes (expert X says this will help the best) to evidence (study Y shows which treatment is best). Evidence-based medicine is not about what someone says, but what we know for sure. A drug or procedure A is better than a drug or procedure B, because investigations have shown it.

In medicine, the mechanism of action of a drug is distinguished from its clinical effect. Similarly, a science of education that has been informed by brain sciences should distinguish between mechanisms of learning, on the one hand, and effectiveness of the learning environment, on the other. It is one thing to know which biochemical pathways a drug acts upon, and another to know how many patients with the illness X are better off with that drug as opposed to a placebo.

The science of education should progress in the same way: it is not only important to investigate the basics of learning processes with brain research, but also to examine the possibilities of application, efficacy, and possible side effects. Medicine as a science and an art lives from basic science and practical application through which it becomes clear what helps and what does not, which theories are useful and which not, which processes are important and which not. Theory alone does not show this.

Thus, it is important to create the conditions for transferring insights from basic studies of learning in brain research to the practice of teaching. In addition to basic research, applied research is necessary and should preferably be conducted by those who do basic research as well (like in medicine), or at least in cooperation with them. This is where I see an important connection to the explorations of personalisation in the public sector and more specifically in education. Personalisation implies, at least in part, a strong integration of theory and practice – or learning through doing. Even though we still know relatively little about brain functioning, we know enough to bet on the fruitfulness of personalised learning with one way of getting started to be through a neuroscience-based understanding of education.

References

Barinaga, M. (2000), "A Critical Issue for the Brain", *Science 288*, pp. 2116-2119.

Chang, E.F. and M.M. Merzenich (2003), "Environmental Noise Retards Auditory Cortical Development", *Science 300*, pp. 498-502.

Elbert, T., C. Pantev, C. Wienbruch, B. Rockstroh and E. Taub (1995), "Increased Use of the Left Hand in String Players Associated with Increased Cortical Representation of the Fingers", *Science 220*, pp. 21-23.

Erk, S., M. Kiefer, J. Grothe, A.P. Wunderlich, M. Spitzer and H. Walter (2003), "Emotional Context Modulates Subsequent Memory Effect", *NeuroImage 18*, pp. 439-447.

Kinsley, C.H. *et al.* (1999), "Motherhood Improves Learning and Memory", *Nature 402*, pp. 137-138.

Lahdenperä, M, V. Lummaa, S. Helle, M. Tremblay and A.F. Russell (2004), "Fitness Benefits of Prolonged Post-reproductive Lifespan in Women", *Nature 428*, pp. 178-181.

Lundborg, G. and B. Rosén (2001), "Tactile Gnosis after Nerve Repair", *The Lancet 258*, p. 809.

McComb, K. *et al.* (2001), "Matriarchs as Repositories of Social Knowledge in African Elephants", *Science 292*, pp. 491-494.

Nakamichi, M., A. Silldorff, C. Bringham and B. Sexton (2004), "Baby-transfer and other Interactions between its Mother and Grandmother in a Captive Social Group of Lowland Gorillas", *Primates 45*, pp. 73-77.

Sear, R., R. Mace and I.A. McGregor (2000), "Maternal Grandmothers Improve the Nutritional Status and Survival of Children in Rural Gambia. Proceedings of the Royal Society of London. Series B", *Biological Sciences 267*, pp. 461-467.

Sear, R., R. Mace and I.A. McGregor (2003), "The Effects of Kin on Female Fertility in Rural Gambia", *Evolution and Human Behavior 24*, pp. 25-42.

Spitzer, M. (2000), "Geist im Netz", Spektrum Akademischer Verlag, Heidelberg.

Spitzer, M. (2002a), "Lernen", Spektrum Akademischer Verlag, Heidelberg.

Spitzer, M. (2002b), "Musik im Kopf", Schattauer, Stuttgart.

Spitzer, M. (2003), "Verdacht auf Psyche", Schattauer, Stuttgart.

Walker, R. *et al.* (2002), "Age-dependency in Hunting Ability among the Ache of Eastern Paraguay", *Journal of Human Evolution 42*, pp. 639-657.

Table of Contents