# WHY THE BRAIN MATTERS

JON TIBKE

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## A TEACHER EXPLORES NEUROSCIENCE

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In memory of Mum and Dad – Jo and Joe Tibke, who were still with us at the start of this project but had both left us before its completion.

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# ABOUT THE AUTHOR

Jon Tibke began his teaching career in Lancashire in 1982, where he taught in four secondary schools over a period of 25 years. Following six years as a deputy headteacher, he moved into initial teacher training, undertaking PGCE roles with the Open University, Edge Hill University and the University of Cumbria. In 2014, Jon became a freelance teacher educator, leading events for trainee, newly qualified and experienced teachers throughout England and Wales, as well as further afield in India, Kazakhstan, Nepal and Qatar. Having finished writing *Why the Brain Matters: A Teacher Explores Neuroscience*, Jon is concentrating on the completion of his PhD thesis, *The Case of Teachers and Neuroscience: How Do Teachers Mediate Information about the Brain?*

# PREFACE

'Are you a neuroscientist?' I was once asked, by an acquaintance who had heard I was working on this book. No, I am most certainly not a neuroscientist, I am a teacher. If teachers are to benefit from neuroscientific findings about learning and teaching and are to actively collaborate with educational neuroscience research, there is a need to understand the issues and complexities from the perspective of teachers. Doubtlessly there is a similar need to understand how neuroscientists conceptualise education. My aim has been to present what I consider to be some of the main issues and complexities of educational neuroscience, writing as a teacher, with largely a teacher audience in mind. Of course, I very much hope that my perspective is of interest to educational neuroscientists. I would hope that they would be patient with any naiveties in my scientific understanding and focus on the possibilities and concerns raised. That is not to say that everything here is new.

Not new, perhaps, but different in some ways to many books about educational neuroscience that I have encountered. For example, it is by design that there is not a 'brain primer' occupying pages of this book. That information is available elsewhere, written by individuals much more qualified to write about it than I am. Several books of this type are cited in various chapters here. I am not convinced that most teachers need extensive neuroanatomical knowledge and for this reason I have sought to offer such information only when it is essential to understanding the text. For chapters where this occurs, there is a short glossary at the chapter's end. The glossaries are of an introductory nature and interested readers are encouraged to explore further.

A daunting characteristic of educational neuroscience, and neuroscience in general, is the sheer volume of research that is emerging daily. Clearly, it is not possible to explore the vast research in any one book and it has been necessary to be highly selective. There is a great deal of exciting new research, significant completed research and legions of highly skilled researchers that it has not been possible to include and that I hope readers will go on to explore further, supported by guidance offered within the book.

Whilst working on this book, it has become increasingly clear to me that we are not on the verge of a complete pedagogical overhaul as a result of neuroscientific discoveries. Changes will come about slowly and through collaboration. Teachers must be key players in considering the pedagogical implications of neuroscience. I hope this book provides encouragement and support for teachers and brings further perspectives to educational neuroscientists in this collaborative endeavour.

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All the teachers who have shared their thoughts and questions about the brain with me.

# 1

# WHY DO YOU NEED TO KNOW ANYTHING ABOUT THE BRAIN?

## IN THIS CHAPTER WE WILL:

- consider the current knowledge of the brain that is of potential value to teachers
- examine the issues and difficulties that this knowledge presents
- explore where else in the book these issues are examined

This chapter explores this pertinent question – just why do teachers need to know anything about the brain? After all, for centuries there have been excellent teachers who have known very little, or even nothing at all, about the brain and this is still the case. In addition, there are things that scientists, teachers and the public previously understood about the brain that more recent research has shown to be entirely incorrect. Conversely, having up-to-date, accurate knowledge of the brain in itself does not make anybody a great teacher. As Chapter 4 demonstrates, there is still plenty of confusion and misinformation about the brain to be found amongst teachers and the general public and many of those who have taken part in some of the research that reveals this actually are highly effective teachers.

## Brain in Research

In the fast-moving, technological, information-laden times in which we live, however, it would be both foolish and a missed opportunity for education if the teaching profession chose to ignore or dismiss the constantly expanding body of research about the human body's most complex organ, the brain, even though the research comes, or should come, with many notes of caution. Overarching the many branches of neuroscience research and the myriad questions about the brain that this research seeks to answer, we have the European Union's Human Brain Project that has run since 2013 and in the USA the Brain Research through Advancing Innovative Neurotechnologies (BRAIN) Initiative, both of which have huge funding. This is a reflection of the hopes and aspirations, particularly for health and education, that neuroscience generates.

This is not to suggest that to keep abreast of this research is by any means easy, as the research is inevitably highly complex, specialised, and laden with language unfamiliar to all but those working in the field. It is unrealistic to imagine busy teachers having either the time or the specialised knowledge to explore this research and in many cases, even with the growing support for *open access*, the research is not readily available for teachers or the public to access. Even when it is, it is often frustrating for teachers who do attempt to study it, since it seldom contains findings that are directly transferable to the classroom. It is also the case that a considerable quantity of the research does not set out to have anything to offer the field of education in the first place, as its relevance may be in other areas such as health or simply in increasing understanding of brain anatomy and processes. For example, a huge amount of research is examining a large number of brain issues relating to dementia and Alzheimer's disease. A lot of research is initially a long way from being applied beyond the laboratory. In a recent example, researchers from the University of California, Los Angeles, the University of California, San Diego and the Icahn School of Medicine, New York, have developed a procedure that has enabled them to study the behaviour of the chemicals that constitute **neurotransmitters**, in the brains of mice. Hitherto, it has been possible to see the neurotransmitters firing in **synaptic activity**, but not the actions of the chemicals themselves in anticipation of and after synaptic activity. The researchers created 'cell-based detectors', able to 'sense the release of specific neurotransmitters in real time', enabling the researchers to see what the chemicals were doing before and after they are active in synapses. In a press release (22.8.16) the American Chemical Society explained that mice learned to associate the sound of a bell with the receipt of sugar, in the manner of Pavlov's classic dog experiment. The reward-related neurotransmitter **dopamine** was initially only visible upon receiving the sugar but once the bell sound/sugar association was learned the dopamine became present at the sound of the bell, thus creating the reward in anticipation of the sugar. In the long term, the press release suggests, the researchers may be able to identify further aspects of how learning occurs and possibly contribute to how addiction is understood and treated. Ultimately, this would require methods to manipulate the neurotransmitters where there are malfunctions of this process in the human brain. Notably, the abstract presented for the American Chemical Society's meeting makes no such suggestions, choosing to concentrate instead on the development of a means of observing the neurotransmitters' **neuromodulators**. When we consider many research projects from an educational viewpoint, we have to recognise first of all that many projects work with mice and other creatures, but we cannot say for certain that the observed processes are identical in human brains, no two of which are identical either.

## Brain in the News

This complicated example leads us to a fundamental difficulty that accounts for the first purpose of this book: if teachers are unable to consider the research in its original format or even begin to identify which research may be of significance, then they are susceptible to over-simplified and exaggerated reporting of complex and often tentative research findings and need to know where reliable digests of the research can be found. This is the theme of Chapter 5, a chapter that also acknowledges how news media in general love a good brain story and how journalistic licence has contributed to some of the myths about the brain that are examined in Chapter 4. An example from *The Times* (Appleyard, 2016) used some now out-of-date research on mirror neurons in monkeys to then explain why people in the UK so much enjoyed the medal-winning achievements of UK Olympians at the Rio 2016 Olympic Games. Apparently, mirror neurons caused UK citizens to believe that they had won the medals themselves and in so doing were personally a part of the medal table challenge that saw the UK finish above China. This was received with both amusement and irritation amongst neuroscience networks – networks with which many readers of the article may well not be familiar. Our teachers are free to read whatever they choose, so are as likely as any other members of the general public to read inaccurate accounts of research, or research used to support other claims that are nothing to do with the research itself. Such accounts are by no means restricted to any particular type of news media and can be seen in broadsheets, tabloids and their online equivalents, video channels, discussion forums and a whole array of websites. Inevitably, such distorted versions of research find their way into books and onto websites specifically aimed at the teaching profession. Education is a broad, competitive marketplace and the scientific allure of education products labelled 'brain-based' has often proved irresistible, as it lends such an air of scientific authority to the products and the learning and teaching methods they espouse. Frequently the resulting classroom fads have later been revealed to have a limited, questionable or even non-existent research and evidence base. This sometimes generates cynicism, as it did on the very active Twitter account of @TeachersToolkit, which in July 2016 asked 'what will teachers be wasting their time on next?' It should be noted, however, that teachers have often learned from such fads, when they and their schools have developed the capacity to critically assess the actual impact and longer term efficacy of the so-called 'brain-based' strategies, beyond the inevitable initial response to the novelty of a new strategy. The term 'brain-based' itself deserves critical consideration: what form of learning does *not* involve the brain? Sometimes the term is used legitimately in an attempt to reflect efforts to find relevant neuroscientific evidence to underpin learning and teaching methods, but there are others who use the term less responsibly to try to add a scientific authority where it does not really exist.

## Teachers as Critical Consumers

Encouraging this criticality is the second purpose of this book. I contend that the era in which teachers might choose to ignore information about the brain's role in the processes of both learning and teaching has passed, as the research is now so extensive, and schools and teachers need to become 'critical consumers' (Sylvan and Christodoulou, 2010). Part of this criticality is the recognition that there is nothing teleological about neuroscience – we should not expect it to become a one-stop, sole source of our understanding of learning and teaching. Yet teachers have commented to me, as a result of my interest in this topic, that at some stage in the future I will be in the enviable position of 'having all the answers'. This will most certainly not be the case and neuroscience will always be one, but only one, of a rich array of disciplines that contribute to our understanding of learning and teaching. As learners and teachers, we are not simply just a brain, nor is the brain the 'executive controller' that it, or at least its cerebral **cortex**, is often portrayed to be. 'Executive controller' is one of many analogies that in themselves deserve further consideration. Although they can aid our understanding they can also draw in conceptual dimensions that are not accurate: your brain is not a computer, nor is it a muscle. The originators of these expressions did not say that the brain was a computer or a muscle; they made analogies that as they are passed on have become distorted.

Our brains do not always respond in the most helpful ways – witness the panic a high stakes examination can induce even amongst well-prepared students or the growing concerns about mental health amongst the school-aged population. We can, however, teach our students about what we understand to be happening in their brains on these occasions and show them how they can use mental and physical strategies to alleviate panic or destructive thought patterns. In a book written for teenagers and clearly stating 'I am not a scientist' (acknowledgements) and with the guidance of a remarkable array of experts, Nicola Morgan presents further guidance in *Blame My Brain* (2013). Key information and sources for students are considered in Chapter 3 of the present volume, where we will pick up the question of whether the implications of Morgan's book title are ones that we should accept, as well as considering helpful brain-related information and sources for students.

## Schools as Research Participants

A third key reason for schools and teachers to be encouraged to engage with neuroscience (and for a book such as this) is the fact that, like it or not, schools, teachers and their students are inevitably part of the research. This is not just a question of acting as research subjects, but rather, as John Geake hoped would happen, being participants who 'contribute educationally relevant questions to the neuroscience research agenda' (2009, p. 189). This poses some significant challenges, most notably in the development of shared understanding and language. Edelenbosch et al. (2015) raise concerns about the difficulties that collaboration presents. There is an extensive body of research focusing on the boundaries and bridges between education and neuroscience. At present, there is little research using classes of pupils, in school, as subjects or participants. One of the reasons for this is the many ethical issues that research on the brains of children raises, aside from the fact that laudable as it may be for a school to take part in such research, it is unlikely to assist the school with its more immediate pressures of accountability and may well be seen as an additional burden by already over-stretched school staff.

There is, however, a growing interest in research to be found in UK schools. This interest appears to place its emphasis largely on evidence that a particular approach to learning and teaching has a positive impact on pupil outcomes, with a view to then trialling it further in the differing contexts of individual schools. The Research Schools Project, funded by the Education Endowment Foundation, adopts this approach. The Education Endowment Foundation, in partnership with the Wellcome Trust, funded six research projects in 2014 that have attempted to conduct research in schools. There is much to learn about how educational neuroscience researchers and educators collaborate effectively. It would seem that in 2011 Anderson and Della Sala thought that such a working relationship was quite some way from development and went as far as to suggest that 'interaction' of neuroscientists and teachers is 'nearly always constituted by the former patronising the latter' (p. 3).

## Lab to Classroom

It is not just in relationships between these fields that this collaboration has proved difficult. The difficulties are also evident in some of the existing literature that attempts to 'translate' neuroscience into useable strategies for the classroom. I should point out that the following comments are intended to illustrate this difficulty; they are not intended to imply that the books under discussion are poor books. On the contrary, they each have worthwhile content and are books I was excited to receive and read. The first is Pat Wolfe's *Brain Matters: Translating Research into Classroom Practice* (2001), which sets out in part one to share information about brain function and structure and then in part two turns to sensory input and information storage. Though some of this would be presented differently and would use different language now, it is accurate for its time. The difficulty arises when part three attempts to match 'instruction to how the brain learns best'. From here on, there is limited reference to the content of parts one and two, reflecting just how difficult it actually is to discuss brain knowledge concurrently with classroom strategy. One might conjecture that the ideas in part three of the book can be put into practice quite successfully without engaging much or at all with parts one and two.

Perhaps the most valuable section of Wolfe's book is the preface, in which she raises important questions and considerations. She promotes caution amongst those interested in bringing learning from neuroscience into the classroom, since 'educators have a history of jumping on bandwagons' (p. v). She rightly points out that there is a great deal we do not know about the brain, but it would be 'foolish to wait until all the research is in' (p. v) before considering how the research might influence classroom practice. In any case, it is most unlikely that we will ever reach such a position and even if we could we would not know. It is to Wolfe's credit that she advises that her book 'contains more caveats than definitive answers' (p. viii).

Tracey Tokuhama-Espinosa's book, *Mind, Brain, and Education Science* (2011) displays her highly impressive command of a vast amount of research, as well as her informative knowledge of the working contexts and professional interests of many key names in the field. Her claims and suggestions are well grounded in a wide array of publications. For anyone interested in the brain from an education perspective, the book is worth reading even just for this. Queries arise however, firstly with the subtitle: *A Comprehensive Guide to the New Brain-based Teaching*. As noted earlier, the term 'brain-based' has been increasingly challenged, since any form of learning involves the brain and the term embodies the dangerous implication that ultimately the brain is the key to all questions about learning and teaching. As I state in several places in this book, it is one of a variety of keys and not a one-stop solution that either now or in the future will hold precedence over all other knowledge and theorising about educational processes.

Like Wolfe, Tokuhama-Espinosa believes that what she refers to as *MBE Science* (Mind, Brain and Education Science) goes a long way to identifying what it is that the best teachers do that brings about their effectiveness: 'using MBE science, we can now explain neurologically in many cases why the things great teachers do work' (p. 205). The qualifications in this sentence are important: Tokuhama-Espinosa clarifies that these explanations are 'neurological', so presumably not representative of the totality of the learning experience and that the science explains 'many cases', implying that there are other things that work that as yet do not sit well with an MBE Science explanation of their efficacy. On balance, it is implicit in her work that the more we understand learning and teaching (neurologically) then the better placed we will be to understand why some strategies work and others may not, as well as being better informed to devise new strategies and interventions.

Something Tokuhama-Espinosa does offer is a 21-point list of neurologically based principles 'that great teachers follow' (p. 206). Amongst these 21 principles are some very worthwhile statements:

> 7. Great teachers know that MBE Science *applies to all ages* (my italics).
>
> 17. Great teachers know that learning relies on memory and attention.
>
> 20. Great teachers know that learning involves conscious and unconscious processes.

In statement 21, we perhaps have clarification of the question of 'neurological teleology':

> 21. Great teachers know that learning engages the entire physiology (the body influences the brain, and the brain controls the body).

It can be argued that some statements need further qualification:

> 12. Great teachers know that learning is advanced by challenge and inhibited by threat.

This assumes that teachers recognise the correct level of challenge and whilst I would not suggest that pupils should be threatened, there is acceptance that a certain degree of pressure or stress is a motivating factor.

Tokuhama-Espinosa does more than present these as a list; she discusses each in well-referenced detail. I have found the 21 suggestions effective in raising discussion in teacher development sessions.

Both Wolfe and Tokuhama-Espinosa propose that teachers need a basic understanding of brain function and anatomy in order to understand neuroscientific literature relating to learning and teaching, and they both suggest that this understanding should in turn support the essential criticality that can protect teachers from fads and bandwagons. Tokuhama-Espinosa makes an interesting case for teachers having knowledge of neuroanatomy that helps them understand why children might have difficulties with tasks that appear to require similar skills. She uses the example of aspects of language, citing the work of Argyris et al. (2007) and Kacinik and Chiarello (2007). Their work reveals that spelling and the use of metaphors, for example, involve different neural networks and Tokuhama-Espinosa suggests that awareness of this can help teachers understand why the same child can be good at one aspect of language and less good at another. Tokuhama-Espinosa's book contains other thought-provoking breakdowns of the mental functions involved in key learning skills such as reading, mathematics and creativity (see, for example, her discussion of reading, pp. 180–8).

## Educational Neuroscience

It is useful to note that amongst the neuroscientific research there exists the education-oriented discipline of *educational* neuroscience, or as Howard-Jones (2008a) has called it, neuroeducational research. Work in this field has produced some of the findings that are considered in Chapters 2 and 3. For example, we have improved understanding of what have been known previously as 'critical' periods of brain development in the early years and researchers such as Sarah-Jayne Blakemore specialise in the adolescent brain. Blakemore's work has done much to realign discussions of the challenges of the teenage years, bringing a brain development dimension to a debate that has tended be dominated by the hormonal impact of adolescence. A team from the University of Cambridge's Department of Psychiatry, using data from brain scans of 300 14- to 24-year-olds, has also considered which brain areas undergo the most significant changes during these years and in so doing have begun to identify links between these developments and susceptibility to mental illness, specifically schizophrenia (Whitaker et al., 2016). As Daniel Goleman (2013) has noted, as well as the developments that we might normally expect in the brains of adolescents, their brains are also adapting to environmental change more rapidly than ever, particularly through extensive contact with information technology and social media. During 2016, media including *The New York Times, The Sun* and the *Daily Mail* featured alarming, exaggerated reports claiming that teenage use of iPads is causing addiction to technology. This is based on the faulty logic that since addictive substances such as heroin and cocaine cause the release of the so-called pleasure neurotransmitter dopamine and using iPads can also cause the release of dopamine, it follows that iPads are addictive. In fact, many activities cause the release of dopamine. I am getting much satisfaction from typing this, so am most likely 'enjoying' some dopamine myself, but I am certain that I am not addicted to this computer. Writing for the website of *yourbrainhealth* (4.9.16), Liv Hibbitt explains the inaccuracy of these newspaper reports in a manner that is both scientifically accurate and highly enjoyable. In the UK, Professor Paul Howard-Jones has been exploring how educators might make positive use of our brains' reward systems and has examined the role of dopamine in particular. James Zull (2011) takes a different approach, tracing the progress of the brain from a biological entity to a fully functioning mind, in a manner that also speaks to the question of age-related development relevant to education. Chapter 6 takes up the question of what these insights from neuroscience offer to the primary and secondary phases of school education, in terms of age-related development.

## Specific Learning Needs/Disability

Whilst research such as that cited above at the University of Cambridge can contribute to our understanding of the risk factors for mental illness in the teenage years, other evidence from neuroscience is informing our understanding of specific learning needs. This echoes the point made above that improving our understanding of educational difficulties can significantly inform the design of interventions and of learning and teaching strategies. In the case of autism, the writing of Temple Grandin has considerably enhanced our understanding of the condition. There is also a considerable amount of research taking place that investigates a variety of potential causes of autism. Like Grandin, Barbara Arrowsmith-Young has written about educational needs from a personal perspective. Both have much to teach us from their understanding of themselves and their brains. In Grandin's case, she undoubtedly possesses one of the most frequently scanned brains of any living individual, as she has for many years been a willing participant and a sought-after subject for the trial of new **imaging** technology. Their stories, explored in

Chapter 8, are powerful testimonies and offer a human perspective that is inevitably not always evident in scientific research papers. Other examples of neuroscience helping with our understanding of special educational needs are considered in Chapter 9. Some aspects of learning appear to have received much research attention, most notably mathematical learning, literacy, the acquisition of first and subsequent languages and music. Also relevant and something that teachers do ask about is whether neuroscience has anything useful to say to teachers about behaviour.

## Medical Imaging Technology

In 1996, writing during what was known in the USA as 'the decade of the brain', Eric Jensen wrote that 'there's an explosion in brain research that threatens the existing paradigms in learning and education' (preface). One can read similar prophecies today, many years after Jensen's claim. But though the supposed 'threat' has failed to occur on anything like the scale that Jensen implies, there is no doubt that neuroscience continues to give us further insights into the complexity of the brain and, notwithstanding the issues of hype and misuse for marketing, that educational neuroscience is becoming more adept at revealing to us how these findings may be of significance. The medical imaging technology that has made much of the research possible has developed enormously in power and accuracy. I recall my local hospital raising funds to obtain a CAT (computerised axial tomography) scanner during the 1980s. Since then, an array of ever more powerful and sophisticated medical imaging machinery has allowed us to look deeper and deeper into the brain and with increasing spatial (the location of activity in the brain) and temporal (the timing of activity in the brain) accuracy. You may have heard of fMRI (functional magnetic resonance imaging), or PET (positron emission therapy); you may also have heard of TMS (transcranial magnetic stimulation) and even of the dangers of DIY versions of TMS (about which the online gaming fanatics amongst your students may well need warning – see Chapter 3); but you probably have not heard of DTI (diffusion tensor imaging) or of the near infrared technology utilised in optical topography, a method through which Hideaki Koizumi ambitiously seeks to understand not just how brains might process the concepts of, for example, biology or mathematics, but also concepts such as love and hate.

Perhaps there is no great need for teachers to be familiar with these individual imaging technologies or have an extensive neuroscientific vocabulary; but though Jensen's revolution has not occurred we do at least have plenty of evidence that gives us neurobiological reassurance for the most effective approaches to learning and teaching, as well as a further tool in the development of pedagogy that should sit alongside educational psychology, cognitive psychology and child psychology, to name but three.

## Teacher Education

In 2015, the Carter Review, a critique of initial teacher training in England, commissioned by the Department for Education and led by Sir Andrew Carter, suggested that there is a case for the formal reintroduction of child development within teacher training programmes: 'Recommendation 1e: child and adolescent development should be included within a framework for ITT content' (p. 9). It would be a considerable oversight if the enacting of this recommendation did not include something of what neuroscience is contributing to our understanding of child and adolescent development. Predating the Carter Review, Paul Howard-Jones (2008b) made a number of predictions concerning the role of neuroscience in education, including predictions he anticipated seeing in place by 2025 and others upon which he speculated emerging beyond 2025. Whatever the timescale, it is implicit in the Carter Review and in the predictions of Howard-Jones that trainee teachers will need to have a framework through which to understand the possibilities and limitations of neuroscience. Such a framework could also help develop the criticality described above, along with the capacity to identify pseudoscience and claims falsely corroborated with research that is not directly related, such as the example from *The Times* mentioned earlier in this chapter. One can only speculate, as Paul Howard-Jones does, as to what the state of play might be in the later years of a teacher who is now at the start of what may be a 35-year, or even longer, career in education.

These and other considerations for the future are presented in Chapter 10. Prevalent amongst these is the potential role in education in the future of genetics, more precisely behavioural genetics, particularly in alerting schools and parents to potential educational difficulty. Teachers tend to find this a controversial topic and it does indeed raise a number of ethical considerations, but as with neuroscience it is a field of which teachers are likely to need some understanding. Kovas et al. (writing in Mareschal et al., 2013) answer their own question, 'what does everyone need to know about genetics?' (p. 78). In doing so, they suggest that one does not have to be an expert in order to understand the key basic messages from either genetics or neuroscience, a point to which we shall return. In fact, neuroscientists too are attempting to produce developmental guidance, for example in the form of brain growth charts (Kessler et al., 2016). Paul Howard-Jones has suggested that we will soon need a new kind of hybrid professional included in the workforces of our schools or groups of schools, that has professional training and expertise both in education and in what he prefers to call 'neuroeducational research'. Imagine a panel at your school attempting to appoint such a person; in such a scenario, there is most definitely a need for a considerably greater understanding of the issues around educational neuroscience than most schools can currently claim to possess. At present, though schools may not be making appointments quite like this, as described earlier in this chapter many schools are creating roles with responsibilities for engaging with research and keeping colleagues informed of research, and there are schools working on projects with universities that include aspects of neuroscience and cognitive psychology. The Wellcome Trust and the Education Endowment Foundation-funded projects (*Teensleep, Learning Counterintuitive Concepts, Fit to Study, Spaced Learning, Engaging the Brain's Reward System, GraphoGame Rime*) are examples. These are mentioned in subsequent chapters, along with other projects that employ varying approaches to the interface of neuroscience and education.

Having read this introduction, you may be drawn to particular chapters or you may prefer to continue on to Chapter 2. Either approach is feasible and I have endeavoured to signpost links between chapters where they arise. One thing I have elected not to do is to include a large section exclusively on brain function and brain anatomy, preferring instead to focus on the key issues for teachers; this book seeks to support teachers in exploring the possibilities and the issues presented by teacher engagement with neuroscience (and vice versa) and does not seek to prepare anyone for a neurobiology examination paper. Inevitably, there is some brain anatomy and function information required for clarification and a brief glossary supports this at the end of chapters. I would urge readers who wish to explore the brain in this manner in more detail to consider some of the excellent sources referenced throughout the book.

### SUMMARY ACTIVITY

- List the key reasons for teachers having some understanding of the brain and educational neuroscience that are proposed in this chapter.
- What is your personal response to these reasons?
- How would you put these reasons to a colleague, a group of colleagues or the staff of your school?

## Glossary

**Cortex:** the outer layer of an organ, in the case of the brain the folded grey matter also known as the cerebral cortex.

**Dopamine:** a neurotransmitter (see below) or chemical messenger released by neurons in several brain areas, associated with movement, attention, motivation and reward.

**Imaging** (medical imaging, neuroimaging): the growing range of techniques for examining and exploring the body and brain. Most commonly used with the brain are fMRI (functional magnetic resonance imaging), computed tomography (CT) scanning, positron emission tomography (PET), electroencephalography (EEG), magnetoencephalography (MEG), near infrared spectroscopy (NIRS), transcranial magnetic stimulation (TMS) and diffusion tensor imaging (DTI).

**Neuromodulator:** neuromodulators reduce or increase excitability in the neurons they affect, controlling the rate of neurotransmitter release. Unlike neurotransmitters, they can affect neurons that are not adjacent to the neuromodulator. They can act for longer than neurotransmitters. Examples include the opioid peptides, such as endorphins and dynorphins.

**Neurotransmitter:** chemical messenger that supports signals between neurons or nerve cells, released across synapses (see *synaptic activity* below). Examples include dopamine, acetylcholine, noradrenaline (also known as norepinephrine), gamma aminobutyric acid (GABA) and serotonin. The latter two examples are *inhibitory* neurotransmitters, which inhibit rather than excite the neuron with which they are communicating.

**Synaptic activity:** where action potentials (nerve impulses) are transmitted, chemically or electrically, between neurons. Synapse refers to the gap between the axon of one neuron and the dendrite of another. An electrical synapse involves direct contact between neurons, whereas in a chemical synapse neurotransmitters communicate across the gap.

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