Praise for *Neuroscience for Teachers*

I wish this book had existed when I was teaching! *Neuroscience for Teachers* is a wonderfully easy read, arming teachers with the most up-to-date research about learning from the fields of neuroscience and psychology.

Lia Commissar, Programme Manager of Education and Neuroscience, Wellcome Trust

A comprehensive and remarkably up-to-date account of the contributions that neuroscience and cognitive psychology are making to teaching practice.

Dr Tim Bliss, fellow of the Royal Society

Neuroscience for Teachers is one of those rare books that manages to blend academic theory with excellent practical advice for the classroom. A timely piece of work, considering the growing interest in applying the knowledge of what we know about the human brain to the field of education.

No stone has been left unturned in sifting through the wealth of evidence available on neuroscience and its implications for education as the authors explore a range of fields of study to deepen understanding of key areas – from memory and metacognition, to emotion, motivation and the enigma that is the typical adolescent brain. There are also a number of 'next steps' and suggestions at the end of every chapter, outlining how teachers might incorporate this evidence into their practice.

Both intuitive and informative, *Neuroscience for Teachers* fills an enormous hole in teacher education with depth, clarity and accessibility, and will satisfy both novice and expert alike. For educators, I'd do more than recommend it: I'd make it mandatory to their professional learning. *Neuroscience for Teachers* will change the way you teach.

Rachael Edgar, senior leadership team member, Latifa School for Girls

Neuroscience for Teachers provides a comprehensive, up-to-date introduction to the key issues, debates, challenges, methods and research findings in the field of educational neuroscience. It is written accessibly and contains everything that a teacher needs to know about neuroscience, describing where this knowledge comes from. Most fascinating are the tips given to teachers, which are very clearly drawn from the evidence base as it currently stands. This has the added bonus of making *Neuroscience for Teachers* a useful resource for researchers who carry out related work but may be stumped when considering how their work impacts upon education.

Whether the reader is a teacher or a scientist, they will come away with a deep understanding of the educational neuroscience knowledge base, how we got there, and how we might use this information in the classroom.

Annie Brookman-Byrne, doctoral researcher in educational neuroscience, Department of Psychological Sciences, Birkbeck, University of London

I've read lots of books about teaching which love to tell you 'how' to teach, but very few – if any – which tell you the underlying reason 'why' each technique is effective. *Neuroscience for Teachers* tells you why effective teaching practices work with a clarity that makes it essential reading for everyone working in schools. The clear explanation of each neuroscientific study empowers teachers to take back control of their pedagogy from the incoherent advice peddled to schools for decades by consultants and/or politicians. The reflections provide an accessible bridge from quite technical neuroscientific findings to practical classroom approaches. I love that it tells you when and why scientific findings aren't applicable to the classroom, and how it exposes the ways in which 'neuromyths' arise in education to help you avoid these pitfalls in the future.

Everyone working in education will find *Neuroscience for Teachers* valuable, and anyone invested in effective teaching and learning should read it.

Emily Giubertoni, Assistant Director, Bishop Challoner Teaching School Alliance

Written in a clear and engaging way, *Neuroscience for Teachers* avoids the trap of overgeneralisation which is so commonly observed when neuroscience is taken outside of academia. The authors introduce the key neuroscience topics relevant to education and describe in detail the evidence available in order to help teachers reflect on how this may benefit their practice. In addition to expanding their knowledge about the brain and cognition, it will also develop teachers' research literacy and improve their ability to assess neuroscientific findings more critically.

I believe *Neuroscience for Teachers* may become a key reference for teachers desiring to better understand and apply neuroscience to their practice.

Dr Florence Ruby, Researcher, Nurture Group Network

The marriage of neuroscience and education is a partnership that is full of potential to improve young people's learning and development outcomes. Drawing upon their experience of collaborating with educators, Churches, Dommett and Devonshire have produced a book that combines the very latest research with useful rules of thumb for teachers and provides examples of how these ideas might be converted into classroom practice.

Neuroscience for Teachers unfolds in such a way that newcomers can stay on the path with just the core ideas, while readers with more experience in neuroscience and education can take side roads and explore the research in more detail. The authors also help teachers avoid pitfalls by pointing out the common and newly emerging misinterpretations and 'neuromyths' that readers might encounter elsewhere.

I am sure that all educators will find some ideas in this book that are affirming, some that are challenging, and others that will inspire creative twists on their existing practice.

Martin Westwell, Director, Flinders Centre for Science Education in the 21st Century

Churches, Dommett and Devonshire offer a wonderfully comprehensive account of the developing relationships between neuroscience and education.

Using clear language with ample illustration, *Neuroscience for Teachers* is written with a keen eye on the professional relevance to teachers and is likely to become the definitive text on this topic.

Ian Menter, Emeritus Professor of Teacher Education, University of Oxford, former president, British Educational Research Association

Neuroscience for Teachers by Churches, Dommett and Devonshire is an invaluable exploration of the growing collaboration between neuroscience, psychology and education – and the potential this offers teachers and schools.

A fantastic introductory guide for teachers in the early stages of their careers, and those interested in evidence-based practice, it serves to develop teacher scientific literacy, negate 'neuromyths' about learning and the brain, and signpost key articles and research for further thought and discussion. The text is positive and accessible without being patronising: the scientific definitions and theoretical introductions are clear and are linked back to practical application to, and implications for, the teacher's own classroom and students. With open questions to consider and a 'Research Zone' focus in every chapter, *Neuroscience for Teachers* helps improve literacy in the vocabulary of neuroscience and helps develop a better understanding of research methodologies.

The eight chapters provide particular insight into metacognition, the adolescent brain and working memory, combined with a focus on the implications and emerging questions for the teacher and classroom. What is particularly satisfying is the recognition that children are unique individuals and that the classroom context is significant: there is no simplification of research and evidence here.

Neuroscience for Teachers is exactly the kind of guide I wish I'd had available to me as a student teacher fascinated by the science of learning, and I can see it being profoundly useful to teachers and those designing CPD, curricula and initial teacher education everywhere.

Rachael Hare, Head of Teacher Training, Harris Federation

It is very clear that neuroscience must be relevant to all involved in teaching: understanding how we learn is fundamental to effective practice. To this end the authors' clear emphasis on evidence-based approaches is highly commendable in recognising the importance of taking proper evidence seriously when seeking to understand what really works in the teaching and learning process. *Neuroscience for Teachers* is centred on that approach and enables any teacher to access the fundamentals of neuroscience easily. All explanations are clear and simple and do not assume a level of knowledge on the topic that would otherwise make it inaccessible.

I would certainly recommend *Neuroscience for Teachers* as a really useful book that would greatly benefit all teachers – at any stage of their career – who have an interest in neuroscience and its importance to teaching. It seems especially relevant to anyone who is training to teach, and it is hard to imagine why any trainee would not find this evidence-based, practical and interesting book highly relevant to their teacher training programme. Reading it would be a very good use of some of their scarce time.

Stephen Munday, Executive Principal, Comberton Village College,
CEO, The Cam Academy Trust

NEUROSCIENCE for Teachers

Applying research evidence from brain science

Richard Churches, Eleanor Dommett and Ian Devonshire

Foreword by Baroness Susan Greenfield CBE

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Foreword by Baroness Susan Greenfield CBE

The school I went to was a very good place to be. It catered for girls from a very wide range of backgrounds and provided lots of opportunities for individuals to develop. Of all the lessons, the one I most looked forward to every week from about the age of 14 was Greek. My teacher, Veronica Lemon, was highly inspirational. She was fresh from university and only about 10 years older than my friends and me, which made her seem much more approachable than many of the more established mistresses. She was fun, lively and excited about the subject – it was totally infectious. Her abilities as a teacher, together with the ideas and philosophical issues of free will and individuality embedded in Greek literature, history and philosophy (together with her skill in teaching the language), put me on the journey towards the type of questions that I have tried to answer in 40 years of research as a neuroscientist. Questions like 'What is the mind?' and 'What is it that makes us individual?' I remain indebted to that inspirational teacher. Of course, you do not need to be a neuroscientist to have had experience of an inspirational teacher at school. But being a neuroscientist, it has been impossible to avoid getting involved in and feeling passionate about education and learning, and what neuroscience might one day offer teachers.

Bearing in mind that we neuroscientists spend so much time thinking about and studying the nature of learning, it has always surprised me that there has not been a deeper collaboration with teaching. So in 2008, with Estelle Morris, we inaugurated an All-Party Parliamentary Group on Scientific Research in Learning and Education to look at how neuroscience and education could begin to talk more to each other and learn from each other. At the end of the first session, I remember saying how I felt sad and frustrated that I had to curtail the discussion. A number of other such sessions took place and it became increasingly clear how important it was going to be that the two fields continued to collaborate.

Nine years on, I am pleased to say that many of the things that we debated have begun to be implemented, such as the wider use of randomised controlled trials in education and clarifying for teachers about what is, and what is not, supported by neuroscience. There are also a few dedicated courses for teachers and the steady growth in texts that help to explain some of the things we have discovered in laboratories about how people learn. Indeed, for the first time, a government minister in England, Nick Gibb, has recently begun to point to some of the available evidence about the science of learning and recommend that teachers engage with it.

This said, and on the communication of science generally, a big issue is always how the evidence gets communicated to the general public or to particular groups to whom it is highly relevant. Educational neuroscience is no different, and despite the fact that a number of excellent books and publications have emerged on the topic, these have mostly remained highly technical or focused on specific areas. The consequence of this is that teachers have been left, to some extent, with no alternative but to read books with a less robust evidence base and which do not survey the breadth of important areas.

What has been lacking until today is a text that provides a suitable bridge for the average teacher to engage with what is accessible, up to date and accurate and does not neglect to read across to education evidence where there is common ground. Richard, Eleanor and Ian's book does exactly this, and represents a major step forward in collaboration between neuroscience and education.

A deeper and wider collaboration between neuroscientists and teachers can only be a good thing, and long may it continue – if only from the perspective of ensuring teachers have accurate information about the brain and what the research evidence actually says. However, far more is possible. The potential for the neuroscience of learning to form a foundation for teacher training is one area that offers further possibilities. As we look across the landscape today, it is clear that education stands on the brink of a great opportunity. This opportunity is not, however, a one-way street.

Neuroscience can also benefit from working with education. The laboratory and the fMRI scanner are not the classroom, and there is an urgent need to extend the range of classroom-based randomised controlled trials that test theories developed in laboratories and universities in real classrooms and with real teachers and children. It is heartening that work has already begun in this space between the Wellcome Trust and the Education Endowment Foundation. This said, there must be multiple replications in different contexts, in different schools and with different children if we are to ensure that we understand the complex world that is the classroom and exactly how this world interacts with our neurology. That teachers can support this journey with their own teacher-led randomised controlled trials (as the authors have already demonstrated in their wider work with teachers) opens the door to an exciting new era in education and neuroscience research.

Preface

Neuroscience, education and evidence-based practice – developing teachers' scientific literacy

Never before has the question of evidence in education been so central to the discussions of teachers and school leaders (McAleavy, 2016). Frequently in these discussions the topic of learning and the brain emerges. Yet, if you had mentioned neuroscience and education 20 years ago, the response would probably have been, 'What have they got to do with each other?'

Today, things have changed considerably and it seems impossible to imagine a future where there will not be a close relationship between the two disciplines. Indeed, it seems likely that neuroscience will one day contribute to education in a similar manner to the way that science has historically contributed to medicine (Thomas, 2013). It is also clear that ideas from neuroscience (accurate and inaccurate) in themselves have an important effect on both teachers and parents, as illustrated in a recent research report by the Wellcome Trust (Simmonds, 2014). Furthermore, as the field of neuroscience uncovers more of nature's secrets about what it means to be human, and particularly the way we learn, we must accept that this burgeoning relationship between the two disciplines will not go away. Therefore, going forward it is imperative that this relationship is an effective one.

A brief review of the current landscape identifies some key foundations that will help to ensure this is the case – if we continue to nurture them. Firstly, several landmark publications (e.g. Blakemore and Frith, 2005; Howard-Jones, 2007, 2010; Geake, 2009; Royal Society, 2011; Deans for Impact, 2015) have helped to guide the relationship between neuroscience and education by pointing teachers to what the actual research evidence suggests and away from many of the myths about learning and the brain that have entered teacher training and popular literature.

> *"… it seems likely that neuroscience will one day contribute to education in a similar manner to the way that science has historically contributed to medicine."*

Building on this, and grasping the importance of the growing evidence, several English and international universities have now made specific postgraduate qualifications available (at MA, MSc and doctoral level). Some of these are based in education departments (such as the qualifications offered at Bristol University, Birkbeck and University College London), while others approach the subject from a neuroscience perspective (as in the qualifications offered by the Centre for Neuroscience in Education at Cambridge University). Internationally, there are programmes at Columbia University, Gallaudet University, Harvard Graduate School of Education, Vanderbilt Brain Institute, University of Alabama, University of Valencia and Wisconsin Educational Neuroscience Lab.

Secondly, we have seen the more extensive deployment of research methods paralleling those used in medicine and clinical practice. Most importantly, a substantial growth in the number of education randomised controlled trial (RCT) programmes: over 800 university-based education randomised controlled trials in the last decade globally (Connolly, 2015) and over 130 commissioned by the Education Endowment Foundation (EEF) in England alone. This is important because, given time and with the repetition of studies in different contexts (replication), such approaches open up the potential for us to develop a much deeper understanding of the effect of different interventions in different educational settings and with different pupil groups – in the same way that the sophisticated evidence associated with clinical practice has been developed with regard to different patient groups and treatments. In many cases, teachers have been actively involved in the trial process, taking on the management of protocols and testing, while collaborating at scale on multiple trials simultaneously. This was illustrated by the Department for Education's *Closing the Gap: Test and Learn Programme* (Churches, 2016; Childs and Menter, in press). Teachers have also, and increasingly, become active researchers themselves with a school and/or public profile (see also Bennett, 2016; Riggall and Singer, 2016).

In turn, some teachers have learned and successfully applied scientific method in the same way that trainee doctors or healthcare workers may often design and implement a randomised controlled trial to understand the process (Churches and McAleavy, 2016). In one case, a randomised controlled trial protocol by James Siddle (a head teacher in Lincolnshire) is now being trialled at scale by the EEF. Being more research-informed allows individuals to critically assess other people's research as part of their evidence-based practice, rather than rely on absorbing the evidence second hand. Such benefits appear to occur when teachers learn to conduct controlled research (Churches et al., in press). In addition, teacher-led randomised controlled trials usually take place over shorter timescales than larger trials and include 'single lesson studies'. This form of trial offers the potential to more easily move across a laboratory protocol from neuroscience and psychology and to facilitate wider replication of a protocol either before being scaled or after conducting a large-scale trial.

Thirdly, meta-analytical data in a form accessible to busy teachers (see Hattie, 2009; Higgins et al., 2012; EEF, 2017) has begun to help us take the first tentative steps towards being able to talk about 'what works' in education with more certainty and in parallel ways to medicine (as illustrated in What Works Network, 2014). Of course, not all the controlled studies have grounded themselves in the existing neuroscience or established cognitive psychology evidence. Despite this, it seems inevitable that as the number of neuroscience-informed pedagogies that are trialled grows, it will become an increasing expectation that any new form of pedagogy should at least be able to ground itself in valid evidence from a current laboratory study.

As we write, six ground-breaking neuroscience-informed large-scale trials are underway in a partnership between the Wellcome Trust and the EEF (see Research Zone 1.1). These types of studies raise the bar for the question of 'what works', as they are both based on valid and reliable laboratory evidence and are being evaluated for efficacy in schools with real teachers and the children they teach on a daily basis. Being in this space for the first time, it also seems inevitable that one day all forms of pedagogy that are promoted to teachers through government materials and programmes, or sold to teachers by commercial providers, will be expected to establish their efficacy through some form of controlled and replicated research.

> *"… it also seems inevitable that one day all forms of pedagogy that are promoted to teachers will be expected to have had their efficacy established through some form of controlled and replicated research."*

Perhaps of most significance, however, is the fact that neuroscientists have started working directly with teachers in designing and conducting school-based randomised controlled trials in real teachers' classrooms and in a way that has involved the teachers themselves in the design of aspects of the research protocol. Here we can perhaps find the two-way street that will result in a closer relationship between the two fields. Although conducted rigorously and with replication, neuroscience evidence comes largely from laboratory contexts, not classrooms; but for any form of applied neuroscience to have real meaning and true value to education, researchers will need to take the next step – collecting evidence from real classrooms. Chapter 1 will look at this area in more depth and the issues that can arise when attempting to transfer laboratory evidence to a classroom context.

Writing a book that aspires to help neuroscience and education interact more effectively and develop deeper levels of collaboration was a challenge. Neuroscience is one of the fastest growing areas of research in the world. At the same time, findings from educational neuroscience research are appearing almost daily in journals such as *Educational Neuroscience, Trends in Neuroscience and Education, Mind, Brain and Education* and a new journal, *Science of Learning* (from which you will find numerous citations here). Because of this, no book that attempts to survey the research evidence and direct teachers to the areas that might be most useful to them could ever hope to be completely up to date. Therefore, we have had to be selective rather than comprehensive and have aimed to include the evidence and information that we believe to be of most direct use to teachers, as the current evidence stands. Alongside this, it is going to be important for teachers to develop their scientific literacy both in terms of the vocabulary of neuroscience and an understanding of the research methods that are used – a point we will return to in Chapter 8.

What’s in the book?

Although we did not know it then, this book began in 2009 with a research project funded by the CfBT Education Trust (now the Education Development Trust). Central to the project was one of the first multi-factor randomised controlled trials in education in England (Dommett et al., 2013; Elwick, 2014), which involved giving workshops on neuroscience to advanced skills teachers from Gloucester. Oxford University’s Department of Pharmacology had submitted a grant proposal to run the project, and Susan Greenfield and Richard had just conducted a series of interviews that had not succeeded in appointing anyone to lead the study. It was at this point that Susan suggested Eleanor and Ian, then working in her lab, to run the project, and we (the three authors) first met. It was clear from the start of the project that the fields of education and neuroscience, although intuitively having something to offer each other, were still worlds apart – indeed, at that time getting across the idea of a controlled research study, even to science teachers, proved challenging and at times it felt like different languages were being spoken.

The chapters in the book evolved over time from our discussions above and in parallel with the work of the All-Party Parliamentary Group on Scientific Research in Learning and Education at the House of Lords, organised by Susan, Ian and Eleanor and also attended by Richard. The opening chapter deals with many of the issues and important questions that arose from those discussions and debates, and tackles the question of the discrepancy between the level of evidence required in the two different fields (from the microscopic to the social). Chapter 2 focuses on the nature of learning, as understood in neuroscience and psychology, and covers areas such as attention and types of memory. Chapter 3 deals with the topic of metacognition and gives a neuroscience perspective on those aspects of this vast area of research that are probably of most interest, noting the fact that metacognitive and self-regulation approaches now have some good education evidence to support them. In Chapter 4, we explain the neuroscience evidence which shows that effective learning needs to be underpinned by the right emotional climate in schools and classrooms. In Chapter 5, in a chapter that looks at individual differences in the classroom, we give an up-to-date summary of the evidence base for important areas of special educational needs and what neuroscience has to say about talent. Chapter 6 explains what we know about changes that happen in the adolescent brain and their implications. In Chapter 7, we return to the important question of what neuroscience can offer in the development of more efficient pedagogies by looking into the so-called ‘desirable difficulties’ research. Finally, Chapter 8 begins by explaining why controlled research is important and then goes on to discuss how neuroscience-informed teacher-led research might be able to make a contribution to the development of a more evidence-led culture, paralleling evidence-based practice in medicine and healthcare.

Throughout the book you will find many academic citations (included in brackets with the authors' names and date of publication). We will also talk about meta-analyses and effect sizes. Some of you will be familiar with these ideas and conventions. However, if you are not, then the next two sections will help you to understand what these are and how we have used them. Depending on your previous experience, just skip the bits that you already understand.

Meta-analyses and effect sizes

In various places we will cite meta-analyses and the effect sizes reported in these. Meta-analyses are scientific reports that analyse a number of individual studies to provide an overall picture of a research field or research area ('meta' has the same meaning as in metacognition and here highlights that the analysis is 'beyond' any simple single analysis). These reviews combine numerical data from a large number of studies in order to make an overall assessment of the effectiveness of a treatment in medicine (or, in education, an intervention).

There are lots of different forms of effect size but the commonest, and the ones referred to in this book, are Cohen's *d* and its very similar counterpart Hedge's *g*, both of which are interpreted the same way. An effect size is used to determine how important a result is, and does this by taking into account the difference between the mean for the two groups (often a control group and an intervention group) while also allowing for how spread out the scores are around the mean and across both groups (i.e. the combined, or pooled, standard deviation; see Figure 0.1). The effect sizes we quote in this book are generally from reports in the EEF's (2017) online Teaching and Learning Toolkit.[1] An effect size of 0.2 is considered a small effect, 0.5 a moderate effect and 0.8 and above a large effect. The EEF, Sutton Trust and Durham University (Higgins et al., 2013) suggest that in longer term studies (e.g. those that last for six months or more) which are measuring attainment, a 0.2 effect size equates to around three months' gain in progress over a 12 month period and 0.5 a seven months' gain. Statistically, a 0.2 effect size represents a difference in which 7.7% of pupils in one group have achieved scores that are above anyone else in the other group; with a 0.8 effect size this rises to 47.4%. Effect sizes can be a positive or negative number (e.g. -0.4). When an effect size is negative it usually indicates that a treatment has had a harmful effect, depending on the control and the intervention. The amount of change between the means and overlap illustrated in Figure 0.1 would equate to an effect size of approximately 0.5 (with around 33% of the intervention group scores not overlapping with the control group scores).

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1 The *Sutton Trust-Education Endowment Foundation Teaching and Learning Toolkit* is led by Professor Steve Higgins at Durham University and involves the systematic review of quantitative evidence from specific areas and presentation of that evidence with regard to information about efficacy, robustness of evidence and an estimated per pupil cost. It is constantly being updated and is available at: https://educationendowmentfoundation.org.uk/resources/teaching-learning-toolkit.

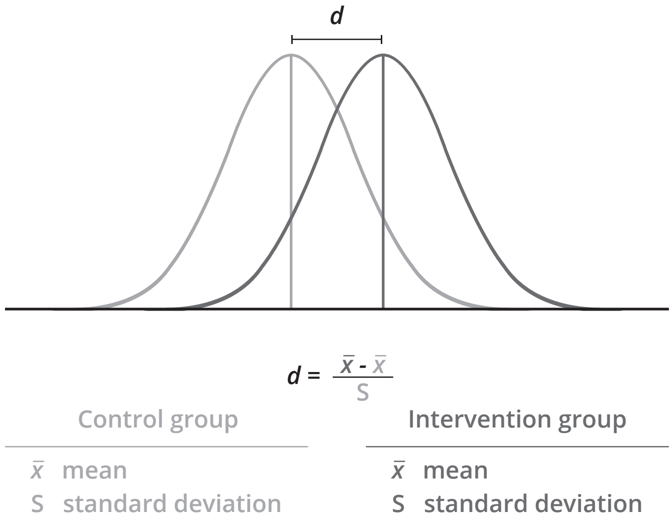


Figure 0.1. How the effect size Cohen's *d* is calculated.

How we have used references in the text and the way in which we sometimes talk about the brain

You will also notice that there are a lot of references in the text, although we have not cited everything that we talk about as you might do in an academic journal. These references follow the Harvard system in which citations are included in brackets after a sentence or within it. This is known as an 'in-text citation' and involves giving the surname(s) of the author(s) and year in brackets to indicate where an idea or statement came from – for example:

> As many writers note, when analysing your data it is essential to use the right statistical test to assess whether your findings are significant or not (Churches and Dommett, 2016).

Sometimes an older reference and an up-to-date reference are included in the same bracket. In these cases, the earlier reference is usually a seminal or important paper and the more recent reference a contemporary update, as illustrated in the following sentence:

> From a psychology and neuroscience perspective, there are three stages in the memory process (Melton, 1963; Dudai et al., 2015).

In these instances, the citation in the brackets tells you where you can find the evidence to support what we have just said or where the idea we have referenced comes from. When you see such an approach the bracketed references are essentially short-hand for saying 'as can be found in/at'. One final convention, also illustrated above, is this – where there are three or more authors we have used the abbreviation *et al.* (e.g. this book would be cited as Churches et al., 2017). This abbreviation is short for *et alia* in Latin, which means 'and others'.

Another thing that you may notice is how we talk about how your brain is doing things in a voice that implies that your brain does these things without your conscious control or 'agency'. There is a good reason for this: most of the time this is in fact the case! Conscious awareness is only triggered by the brain when it is needed because it places high energy demands on the brain. Furthermore, many neuroscientists (based on the volume of evidence to suggest this) increasingly question the extent to which we have any free will at all and propose that although consciousness produces a feeling of agency, in fact this is really an illusion – for the simple reason that conscious awareness happens too late in the process to be the controlling mechanism (Halligan and Oakley, 2000).

Chapter structure and glossary

Each chapter has a similar structure. Alongside the substantive text, we have included several other features. 'Research Zones' draw out particular pieces of research evidence that are of note and make an interesting or important point about the area we have been discussing. There are also 'Reflections' that give you something to think about or suggest something that you might try out in the classroom. In addition, there is a glossary at the end of the book covering many of the technical terms we use. After this preface, each time words covered by the glossary appear for the first time in the text we have indicated this in **bold**.

Contents

Foreword by Baroness Susan Greenfield CBE ... i

Preface: Neuroscience, education and evidence-based practice – developing teachers' scientific literacy ... iii

What's in the book? ... vi

Meta-analyses and effect sizes ... vii

How we have used references in the text and the way in which we sometimes talk about the brain ... viii

Chapter structure and glossary ... ix

List of figures ... xvii

List of tables ... xix

List of Reflections ... xxi

List of Research Zones ... xxiii

1 **Neuroscience in the classroom – principles and practice: getting started** ... 1

Why would you want to know about this? ... 1

What is neuroscience? ... 3

How does the brain work? ... 7

What techniques are used in neuroscience research? ... 11

Neuroimaging in humans ... 13

Techniques in laboratory animals ... 16

Research into mathematics teaching illustrates what neuroscience can bring to education . 18

Maths anxiety ... 18

Non-symbolic and symbolic numerical representation ... 19

Mental rotation skills ... 20

Things that sometimes make collaboration between neuroscientists and teachers difficult . 21

A cautionary tale of what happens when things go wrong ... 28

Misinterpretation of experimental results ... 28

Distortion of scientific facts, normally through the over-simplification of results ... 29

Belief in a previously held scientific hypothesis ... 30

Next steps ... 30

2 **Learning and remembering: attention, learning and memory** **33**
Why would you want to know about this? 33
A neuroscience view of learning and memory 36
Making connections in the classroom 37
Paying attention – what does this mean from a neuroscience perspective? 39
Start with a good headline 42
Inattentional blindness and suggestions for how to avoid it 45
Being careful about how we talk about attention to avoid a new neuromyth 47
Memory processes and structures 48
Memory processes 48
Types of storage (consolidation) 49
The structure of working memory 53
Sustaining attention and the use of working memory in the classroom – social interaction and effective questioning 54
Stages in the process of forming a working memory – implications for the classroom . 56
The structure of long-term memory 58
The role of sleep in consolidating long-term memory 59
From working memory to long-term memory 60
Self-referencing 60
Executive function and recent research into its role in effective learning 61
Chunking and organising information into categories – how and why it can help 63
How your lesson structure could improve the potential for remembering 65
The von Restorff effect 66
The primacy and recency effect 67
Association and repetition – not that again (we hear you say)! 70
Next steps 72
3 **Metacognition: why it pays to teach your pupils how to think about how they think** ... **75**
Why would you want to know about this? 75
Key features of metacognition 77
Phases of metacognition 78
Metacognitive planning 79
Metacognitive monitoring 79
Metacognitive evaluation 79

Cognition versus metacognition 80
Metacognition and ability 81
How the brain thinks about thinking 84
The basis of metacognition from a neuroscience perspective 91
A metacognitive menu 93
Questions that can be posed at each point of a reading comprehension task 95
Planning questions 95
Monitoring questions 95
Evaluation questions 95
Other strategies to support metacognition 96
Next steps 98

4 **Emotions and learning: classroom climate, stress and motivation 101**
Why would you want to know about this? 101
Mood and emotion 102
Types of emotion 103
The neuroscience of emotion 104
Factors affecting mood and emotions 106
Day of the week and time of day 106
Sleep 107
Exercise 108
Manipulating mood in the classroom 109
The body under stress 111
The stress response 111
Factors affecting the impact of stress 113
Stress in the learning context 113
Timing of the stressor 114
Managing stress in the classroom 114
Environmental factors 115
Teacher training 115
Pupil training 116
Motivation to learn 118
What is motivation? 118
Dopamine: a key neurotransmitter in motivation 119

Using risk to motivate in the classroom ... 122
Next steps ... 124

5 **The individual in the classroom: what neuroscience can tell us about different abilities and some special educational needs in the classroom ... 125**
Why would you want to know about this? ... 126
Individuals and neuroscience ... 126
The neuroscience of exceptional performance ... 127
General high intelligence and the brain ... 128
Research on brain volume ... 128
Research using EEG ... 129
Research using PET and fMRI ... 130
Specific talent and the brain – two areas that have been studied recently ... 131
Expert drivers and what studying this has told scientists about ability ... 131
The musical brain ... 134
Short cuts to talent: smart drugs ... 135
The question of nature versus nurture – Part I ... 136
The neuroscience of specific disorders – three areas where neuroscience is making a contribution ... 137
Attention deficit hyperactivity disorder (ADHD) ... 138
Changes in brain structure and function in ADHD ... 140
Treatment of ADHD ... 140
ADHD in the classroom ... 141
Dyslexia ... 142
Changes in brain structure and function in dyslexia ... 143
Dyslexia interventions ... 144
Developmental dyscalculia – a brief note ... 144
Autism spectrum disorder ... 146
Some of the controversies surrounding autism and the challenges involved in studying it ... 147
The brain science associated with autism ... 148
Helping children with autism in schools ... 149
The question of nature versus nurture – Part II ... 151
Grouping by abilities ... 151
Next steps ... 152

6 **The adolescent brain: why teenagers behave like teenagers** **153**
Why would you want to know about this? 153
Peer pressure, or 'Do you realise you don't have to do everything your friends tell you?!' . 155
The importance of being liked 156
The neuroscience of peer pressure 158
Interpreting emotional displays 161
Puberty as a trigger of changes in the adolescent brain 162
Decision-making, or 'Why can't you think of your future for once?!' 163
Youthful short-sightedness 164
Conflicting decisions in the adolescent brain 165
Risk-taking, or 'How could you be so reckless?!' 167
Next steps 170

7 **Surprises from cognitive psychology and neuroscience: why making things more difficult and less enjoyable for students in the short term can enhance long-term learning** **171**
Why would you want to know about this? 171
'Desirable difficulties' – what does this mean? 172
The difference between learning and performance, and why this distinction is so important 173
Changing the way you teach so you vary the conditions to which your learners' brains are exposed 174
Building in time for forgetting by using spaced learning 175
Testing more often and seeing testing as a learning event, not just a way of measuring outcomes 178
Multiple-choice tests and how they can help 179
Connecting the testing effect to learning and remembering 180
The benefits of more frequent testing: some emerging conclusions 181
Interleaving the content you teach 183
Getting the learners to make things up themselves – the generation effect 184
The worked example effect versus the generation effect 185
Next steps 187

8 **Concluding remarks: developing your scientific literacy and understanding of controlled research** **189**
Why would you want to learn more about this? 189
Different types of research 191

What is a randomised controlled trial? 192
What is 'significance', and why is it not enough to just do one study? 194
Where do we go from here? The role that teacher-led research could play in taking the neuroscience evidence forward 195
Next steps 200
Glossary *201*
References *213*
About the authors *250*

List of figures

Figure 0.1. How the effect size Cohen's *d* is calculated. viii
Figure 1.1. The human nervous system. 4
Figure 1.2. The human brain is divided into two cerebral hemispheres with an outer surface called the cortex. 5
Figure 1.3. Division of the brain into four lobes. 6
Figure 1.4. Brodmann's divisions of the cortex. 6
Figure 1.5. The common features of neurons. 8
Figure 1.6. The transmission of signals across the synaptic gap between two neurons. 9
Figure 1.7. The steps involved in scientific method. 11
Figure 1.8. A typical scanner used in neuroimaging. 14
Figure 1.9. A typical EEG set-up and the type of results it produces. 16
Figure 1.10. Levels of research in neuroscience. 26
Figure 2.1. Spot-the-difference puzzles are often a good example of the challenge of inattentional blindness. 45
Figure 2.2. The relationship between sensory, working and long-term memory. 49
Figure 2.3. The structure of long-term memory. 58
Figure 2.4. Using mind/concept mapping to help you organise content into more memorable chunks before you teach (just one way to do it!). 64
Figure 2.5. The primacy and recency effect. 68
Figure 2.6. Achieving more high retention points in a single lesson by breaking the learning up into distinct episodes. 69
Figure 3.1. Phases of metacognition. 78
Figure 3.2. Evolution of the human brain. 87
Figure 3.3. Areas that process language are found where visual processing and movement areas overlap. 89
Figure 3.4. A cognitive hierarchy, also known as the perception-action cycle when each level is connected to a behavioural response (Fuster, 2008; Fleming and Dolan, 2012). 90
Figure 4.1. The six basic emotions are associated with distinct facial expressions. 103
Figure 4.2. The limbic system in the human brain. 105
Figure 4.3. The effects of stress on the body in the alarm stage. 111
Figure 4.4. The inverted U-pattern of responsiveness. 113
Figure 4.5. Different types of reinforcer capable of motivating behaviour. 119

Figure 4.6. The mesolimbic dopaminergic pathway is thought to be critical in motivation. 120
Figure 6.1. A virtual game of 'catch' between the adolescent participant (hand at the bottom of the screen) and two other participants (Sebastian et al., 2010). 156
Figure 6.2. Brain regions involved in how we perceive and react to social encounters. 159
Figure 6.3. Contrasting development of two opposing brain networks that are involved in motivational control. 166
Figure 7.1. Interleaving content. 183
Figure 8.1. Evidence from just the intervention group in a study. 193
Figure 8.2. A very different picture emerges when control group data is compared to the intervention. 193
Figure 8.3. The commonest form of randomised controlled trial. 194

List of tables

Table 1.1. Theoretical barriers to neuroscience and education partnerships. 21
Table 1.2. Comparing what we know about great teaching to some of the findings from neuroscience and learning. 23
Table 1.3. Practical barriers to neuroscience and education partnerships. 28
Table 2.1. The general characteristics of working memory compared to long-term memory. ... 51
Table 2.2. Word lists to use to illustrate the ideas in this section. 65
Table 4.1. The National Sleep Foundation's recommendations for amounts of sleep in school-aged children and their teachers. 107
Table 5.1. The symptoms listed in DSM-5 for ADHD. 139
Table 8.1. Qualitative and quantitative research. 191
Table 8.2. Main findings of Dunlosky et al.'s (2013) review of evidence from cognitive psychology. 198

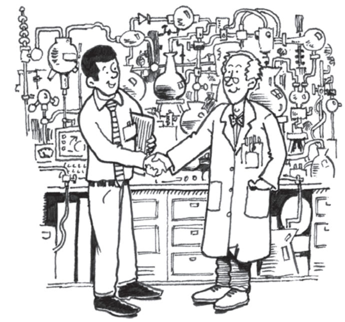
Chapter 1

Neuroscience in the classroom – principles and practice

Getting started

By the end of this chapter you will:

- Understand what neuroscience is and how the brain processes information.
- Understand what kind of research neuroscientists conduct.
- Understand current relationships between educators and neuroscientists.
- Know how to build bridges between the two fields.



Why would you want to know about this?

Have you ever wondered what is happening in the brains of your learners when you teach them and whether this information would be useful to you in developing your practice? Presumably you have or you would not be reading this book. You might be pleased to know that you are not alone in your curiosity about the workings of the brain. The Wellcome Trust recently published a report, entitled *How Neuroscience Is Affecting Education* (Simmonds, 2014), which contains data from a series of surveys with teachers and parents. In one of the surveys, which involved over 1,000 teachers, more than nine out of ten teachers said that their understanding of neuroscience influenced their practice (2014: 1). Furthermore, eight out of ten said they would collaborate with neuroscientists doing research in education (something that is now happening with increasing frequency – see Research Zone 1.1).

Despite this, only 25% of teachers report having a good or fair amount of knowledge about neuroscience, meaning that for many teachers their practice is being influenced by quite limited knowledge, some of which may be inaccurate (2014: 3). One of the reasons we wrote the book is to try to help in this area. Another reason is that our experience tells us that learning about the brain is one of the most exciting types of professional development you can have, and many teachers find it enthralling.

We think there are two specific areas of your teaching that you can enhance by increasing your knowledge of neuroscience. Firstly, neuroscience knowledge can be a powerful way to inform how you teach and understand what happens when your pupils – and, of course, you – learn information and skills. Moreover, neuroscience is not limited to helping you understand learning. For example, it can also provide us with information about **motivation**, mood and the reason why adolescents sometimes appear to belong to a different species. Secondly, neuroscience knowledge can provide you with a theoretical basis for established or new classroom practice, and can help you to evaluate the so-called brain-based learning products that may be on the market. This is important because if you understand the neuroscience evidence, you can spot products that are making claims about being brain-based which are in fact just using neuroscience terminology to sound impressive. In addition, understanding how memory works can help teachers to plan the delivery of content in a way that does not overload the brain's capacity to deal with new information – an area we will spend much time on in Chapter 2. Research Zone 1.1 gives an example of the way in which neuroscience theories have been used to develop classroom interventions and how research programmes can be used to explore their effectiveness.

> *"Eight out of ten teachers said they would collaborate with neuroscientists doing research in education."*

Research Zone 1.1. The Wellcome Trust Education and Neuroscience Initiative

In 2014, the Wellcome Trust launched an initiative with the EEF to explore six areas of neuroscience-informed practice that show the potential to be scalable and affordable for schools. As this book goes to press, the researchers have yet to report the outcome of the studies because the trials are still taking place. Despite this, the topics are worth mentioning as they illustrate the range of areas that neuroscience can contribute to in education. The projects are:

- Fit for study – which is looking at how exercise could improve academic attainment (report due early 2018).
- Spaced learning – an approach in which intense periods of study are alternated with shorter sections of activity containing 'distractor' activities (like juggling); see Chapter 7 (pilot report available at EEF, 2017).
- Teensleep – this is testing the effect of sleep education on attainment (report due September 2017). The programme involves training teachers to deliver lessons to students about the importance of areas such as good sleep-related behaviours, routines and stress management techniques.

- Learning counterintuitive conception – which is applying techniques that may help children to 'inhibit' prior contrary knowledge when learning new ideas in maths and science (report due summer 2017).
- GraphoGame Rime – looking at a literacy improvement programme based on phonics which uses rhyme (report due spring 2018).
- Engaging the brain's reward system – exploring reward strategies in secondary school science classes (report due autumn 2017). This research compares three approaches: game-based questions with uncertain rewards, test-based questions with fixed rewards and conventional teaching (the teacher's usual practice).

The Wellcome Trust Education and Neuroscience Initiative is now being broadened and expanded to include the development of teacher training materials and a range of innovative teacher professional development opportunities. One of these projects involves a collaboration between us and the Wellcome Trust to carry out a series of neuroscience-informed teacher-led randomised controlled trials.[1]

What is neuroscience?

For you to understand how you can apply neuroscience evidence to your teaching, it is critical to understand first what neuroscience is exactly. This question is quite straightforward to answer because neuroscience literally means the science of the nervous system. Here, and from now on, we will use the word 'science' to refer to any knowledge acquired using scientific method. We will discuss scientific method later in this chapter. For now, you just need to know that scientific method is the name given to a process of designing and conducting research that involves making observations and interpreting them in the context of very specific research questions. Importantly, if you have a science background or can just vaguely remember science from your school days, you will already have some knowledge of neuroscience because it makes use of the principles and many techniques from the main science disciplines of physics, chemistry and biology.

Now we have the science part covered, we will look at exactly what we mean by the nervous system. Figure 1.1 shows a simple diagram of the human nervous system. As you can see, there is a central part, comprising the brain and the spinal cord, and then many branches that extend throughout the body. The central part is the **central nervous system** (brain and spinal cord) and everything else is the **peripheral nervous system**.

1 Find out more about these projects and the activities that are taking place as part of this initiative on the Wellcome Trust website: www.wellcome.ac.uk.

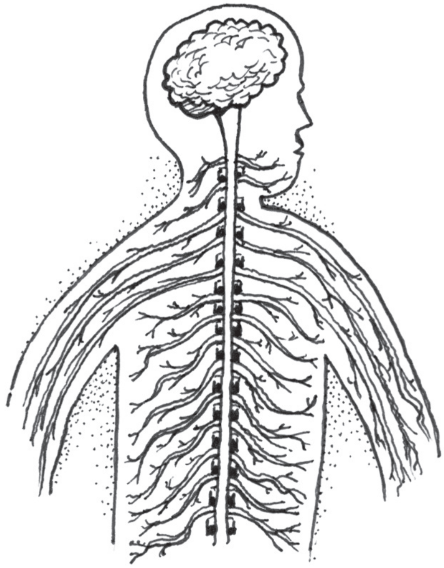


Figure 1.1. The human nervous system.

Although neuroscience is technically the study of the whole nervous system, much of the research neuroscientists carry out aims to investigate the brain. Because this type of research is of most relevance to education, the remainder of the book focuses on research about the brain rather than the whole nervous system.[2]

The appearance of the human brain is not unlike a walnut, with a wrinkly outer surface called the **cortex**. In vertebrates the whole brain can be divided into two cerebral hemispheres (illustrated in Figure 1.2). These cerebral hemispheres, sometimes referred to as the left and right brain, are separated by a fissure that runs from the front of the brain to the back. Beneath the cortex are hundreds of other structures, including the examples shown in the figure.

2 If you are interested in reading more about the entire nervous system there are some excellent neuroscience textbooks available (e.g. Breedlove et al., 2013), as well as brain books that are aimed at the general reader (e.g. Carter, 2009 – with many examples and illustrations; Greenfield, 2016).

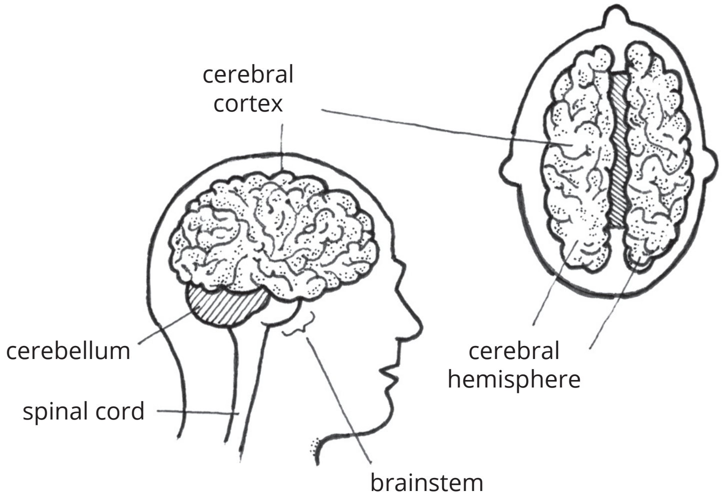


Figure 1.2. The human brain is divided into two cerebral hemispheres with an outer surface called the cortex.

Neuroscientists have divided the brain up according to structural details and the 'job' that is being done in the different areas. One of the simplest approaches divides each hemisphere into four different lobes (see Figure 1.3). The **frontal lobes** are immediately behind the forehead and include areas that are involved in behaviour, personality, learning and voluntary movement. The parietal lobes, at the top of the head, play an important part in the reception and processing of sensory information, while the occipital lobe is the brain's visual processing centre. The temporal lobe is mainly involved in hearing and selective listening, but also has a role in other functions such as memory.

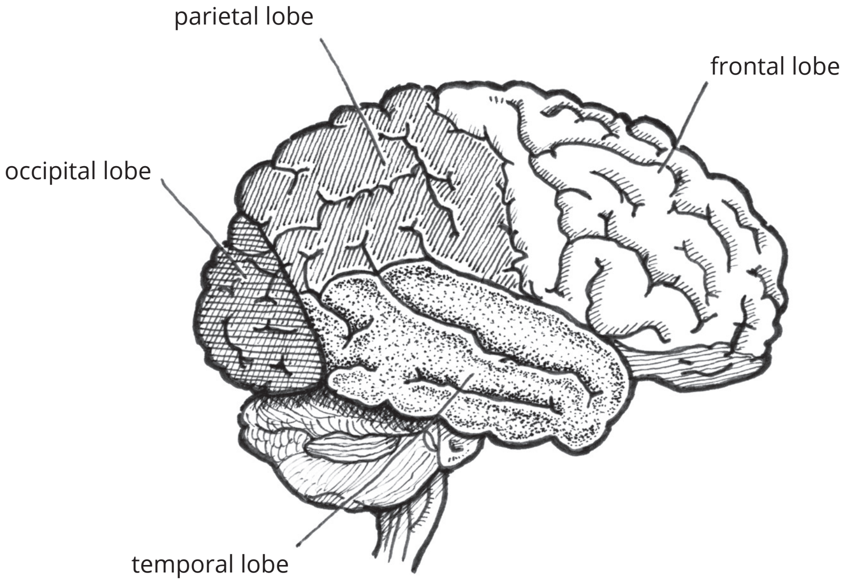


Figure 1.3. Division of the brain into four lobes.

A slightly more complex approach to distinguishing between different brain areas was undertaken by an anatomist called Korbinian Brodmann, who divided the cortex into 52 different areas which he believed to be distinct (Brodmann, 1909). Figure 1.4 shows some of Brodmann's areas (note that not all 52 can be seen from this lateral view). Other divisions are also used.

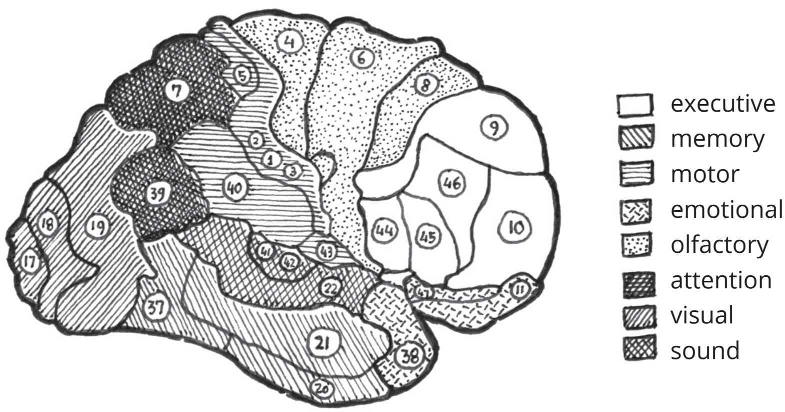


Figure 1.4. Brodmann's divisions of the cortex.

With regard to classroom learning, the whole brain functions in a very integrated way and so you may never need to think about these basic divisions. You may also be pleased to know that we do not intend to cover much more neuroanatomy in this book, although at points we will refer to some key structures and provide a little more anatomical detail where it is helpful.

How does the brain work?

The first thing to consider when thinking about how the brain works is to ask yourself: what does my brain do? You could come up with many answers to this question. Here are just a few:

- Allows us to move around.
- Processes sensory information.
- Controls our vital functions, like heart rate.
- Enables us to communicate.
- Allows us to remember things.
- Makes us who we are.

The last one in the list above is particularly important and we hope that as you work through this book you will begin to appreciate just how individual our brains are. All of these functions can be affected by brain injury and, indeed, it has often been through the study of people with various forms of brain damage that we have begun to understand more about how the brain works and what it does.

> *"With regard to classroom learning the whole brain functions in a very integrated way …"*

From these answers, it is probably clear to you that the brain must process and store all kinds of information. To do this the 1.5 kg adult human brain (Azevedo et al., 2009: 535) contains around 170 billion specialised cells (Herculano-Houzel, 2009: 6). The most important of these for us to consider here are cells called **neurons**. There are about 86 billion neurons in the adult human brain (Azevedo et al., 2009: 535). Neurons are responsible for most signals transmitted around the nervous system. The exact structure of neurons varies considerably but they tend to share a few common features. You can see an illustration of these common features in Figure 1.5.

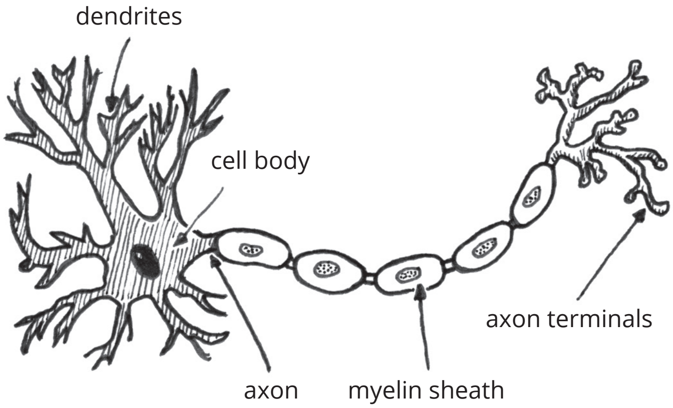


Figure 1.5. The common features of neurons.

The structural features illustrated allow neurons to send signals very effectively. They do this in two different ways. The first way is by generating and propagating an electrical signal that travels within the axon of a neuron. People sometimes call this signal a ‘nerve impulse’ or ‘neuronal firing’ but it is more correct to refer to this as an **action potential**. The signal travels from the cell body to the axon terminals and can reach speeds of 120 metres per second – or, put another way, an astonishing rate of 268 mph (Elmslie, 2010: 9). A special layer of fat called **myelin** is wrapped around the axon, which we come on to later. It has a particular importance in the teenage brain (see Chapter 6).

The second way neurons send signals is through tiny connections with neighbouring neurons. Each neuron has many thousands of these connections and these normally function using chemical signals. When the action potential reaches the axon terminals it causes the release of special chemicals called **neurotransmitters**. These neurotransmitters then attach to receiving molecules on the neighbouring neuron called **receptors**. This restarts the process in the neighbouring neuron with an electrical charge. Receptors are located on the end of a neuron’s dendrites, parts of the cell recently found to have a much more active role than had previously been thought (see Research Zone 1.2). This, in turn, may cause another action potential, and so the signal continues. We call the gap between neurons across which neurotransmitters travel the **synapse** (see Figure 1.6).

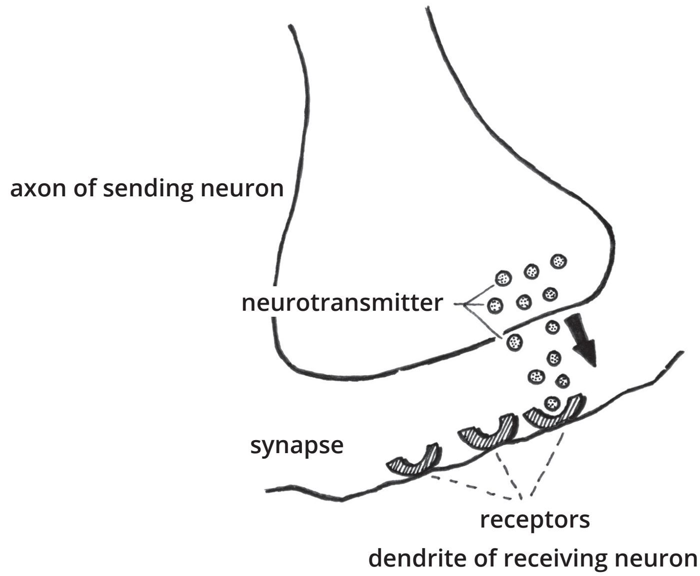


Figure 1.6. The transmission of signals across the synaptic gap between two neurons.

Research Zone 1.2. Dendrites do much more than was previously thought

A very recent finding illustrates some fascinating new information about neurons, as well as illustrating the fact that researchers are making major advances in the field of neuroscience every day. Although neuroscientists previously thought that the cell body of a neuron was the main initiator of electrical signals, it now appears that dendrites initiate up to 10 times as many. This upends previous scientific thinking in which dendrites were essentially passive receivers of information. It means that the brain might have hundreds of times more computational power compared to the previous model in which cell bodies were thought to 'make all the decisions'. It also appears that dendrites can exhibit slow fluctuations in voltage, meaning they can operate in a subtler analogue way, as well as the solely digital (on/off) way in which cell bodies operate (Moore et al., 2017). These findings represent a major departure from what scientists have believed for the last 60 years and illustrate just how much is being uncovered about the brain on an almost daily basis.

"… the brain displays an ability called plasticity which means that it can literally be moulded based on experience."

This electrical and chemical communication is how neurons and therefore the brain transmits information. But how does the brain store information? These processes are complex and would take us into too much detail at a biological level than we need here. For the purposes of our discussion, what you need to know is that the brain displays an ability called **plasticity** which means that it can literally be moulded based on experience.[3] This 'moulding' may be in the form of having more neurotransmitters released in certain places or having more receptors to which the neurotransmitters can attach (as illustrated in Figure 1.6). It can even mean that the brain makes more neurons. In this book, there is no need to go into detail about the exact type of changes that may take place, but it is safe to say that these changes occur as the brain learns and are maintained all the while the brain 'remembers' the information. In many instances these changes are taking place automatically and without any conscious effort (e.g. getting to know someone seems to happen almost effortlessly just by meeting them several times; however, other content, like much of the subject knowledge that we aim to put across as teachers, needs conscious effort if it is to be remembered).

"… electrical and chemical communication is how neurons and therefore the brain transmits information."

Aiming to further understand transmission and plasticity, as well as other fundamental processes in the brain, both in health and disease, forms the bulk of neuroscience research. However, neuroscientists also look at the brain basis of **cognition** (an area of neuroscience conveniently called cognitive neuroscience). Cognition is a broad term that at its simplest refers to thinking. This said, it is more common to see specific **cognitive functions** referred to in studies rather than cognition as a whole. These functions include reasoning, attention, remembering and skills such as reading. Neuroscientific research into these functions can have particular relevance for education and we will cover much of this area in the rest of this book. Before we move on to look at how neuroscience and education relate to each other we are going to briefly discuss the kind of techniques used in neuroscience.

3 Three main areas of plasticity have been established: (1) plasticity of nervous tissue, therefore the brain remains plastic right into old age (e.g. Buonomano and Merzenich, 1998; Weinberger, 1995); (2) plasticity at a neuronal level can enable people to recover from some forms of brain damage (Taub et al., 2006; Cicerone et al., 2011); and (3) plasticity occurs in relation to normal learning processes both motor and cognitive (Maguire et al., 2000; Draganski et al., 2004).

A major step forward in collaboration between neuroscience and education.

Baroness Susan Greenfield CBE

A wonderfully comprehensive account ... Likely to become the definitive text on this topic for teachers.

Ian Menter, Emeritus Professor of Teacher Education, University of Oxford, former president, British Educational Research Association

In *Neuroscience for Teachers* two neuroscientists and a leading education writer expertly unpack, in an easy-to-read and instantly useable way, the latest research on the things that will help your learners to learn better.

As the field of neuroscience uncovers more of nature's secrets about the way we learn – and further augments what we already know about effective teaching – this book advocates using more efficient pedagogies rooted in a better understanding and application of neuroscience in education, and shares up-to-date information in relation to:

- The nature of learning and types of memory
- How the right emotional climate boosts learning
- Catering for individual differences and special needs
- Improving learners' metacognitive powers
- Exposing learners to desirable difficulties
- Understanding the developing teenage brain

With its worked examples and suggestions as to how to enhance personal effectiveness and improve classroom delivery, *Neuroscience for Teachers* provides accessible, practical guidance on what every teacher needs to know about the brain and how we really learn – and what that suggests for how they should teach.

I wish this book had existed when I was teaching! A wonderfully easy read, arming teachers with the most up-to-date research about learning from the fields of neuroscience and psychology.

Lia Commissar, Programme Manager of Education and Neuroscience, Wellcome Trust

A comprehensive and remarkably up-to-date account of the contributions that neuroscience and cognitive psychology are making to teaching practice.

Dr Tim Bliss, fellow of the Royal Society

It will change the way you teach.

Rachael Edgar, senior leadership team member, Latifa School for Girls

Whether the reader is a teacher or a scientist, they will come away with a deep understanding of the educational neuroscience knowledge base, how we got there, and how we might use this information in the classroom.

Annie Brookman-Byrne, doctoral researcher in educational neuroscience, Department of Psychological Sciences, Birkbeck, University of London

Everyone working in education will find this book valuable, and anyone invested in effective teaching and learning should read it.

Emily Giubertoni, Assistant Director, Bishop Challoner Teaching School Alliance

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Dr Richard Churches is lead adviser for education reform and evidence-based practice at Education Development Trust.

Dr Eleanor Dommett is a neuroscientist at King's College London where she conducts research into the neural basis of distractibility.

Dr Ian Devonshire is a neuroscientist and science communicator based at the University of Nottingham. He lectures on neuroscience and mental health at the Open University.

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