1 Why Educational Neuroscience?

Our brains did not evolve to go to school. Yet we do all go to school as students, and some of us return as teachers. For that matter, our brains did not evolve to enable us to cope with most of the requirements of modern life. Yet we do. The human brain is composed of thousands of functional modules, mini-brains within a brain, most of which evolved in our distant pre-hominid past. It is through multiple, complex combinations of these functional modules, through a myriad of interconnections, that our brains create functional neural systems which enable us to adapt and succeed at tasks which our ancestors could not have even dreamed about. For several hundreds of years, such tasks have included formal education, both as learners and as teachers. More recently, one of the activities which some of our brains have turned to has been research into how our brains function. That's neuroscience. Within neuroscience, a central focus has been how our brains enable us to think. That's cognitive neuroscience. And within cognitive neuroscience, a particular interest is how our brains enable thinking in educational contexts. That's educational neuroscience. To be precise:

> *Educational neuroscience is cognitive neuroscience which investigates educationally inspired research questions.*

In other words, educational neuroscience is cognitive neuroscience that is relevant to, has implications for, and might lead to applications in, educational practice and policy – pedagogy and curriculum – because the neuroscience addresses an educational problem or issue. Consequently, educational neuroscience, as a research endeavour, only makes sense if the genesis of its projects lies in educational issues, concerns and problems. Without being rooted in education, neuroscientific data and interpretations are unlikely to be embraced by the education profession. Therefore, I suggest, educational neuroscience should incorporate an action research cycle wherein the original educational issue inspires a set of neuroscientific research questions, the results of which are likely to have implications and applications for educational policy and/or practice. For the latter phase, the research cycle is not complete until the putative applications have been field-tested in classrooms. Of course, the outcomes of this might lead to a revision of the articulation of the original educational issue such that a whole new raft of neuroscientific research questions arise, and another research cycle is initiated. That is, a discipline-specific methodology for educational neuroscience needs to be established. Here are four examples.

1 Education problem: the watershed of fractions.
   - Neuroscience research: neural dissociations and connectivity between concrete and symbolic representations of fractions.
   - Possible education application: design of more efficacious curricula for symbolic fractions.
2 Education problem: the decline in second language studies in secondary schools.
   - Neuroscience research: neural dissociations and connectivity between orthographic and phonemic representations of first and second languages.
   - Possible education application: design of more efficacious curricula for second language acquisition in primary schools.
3 Education problem: how to optimize creative thinking in school.
   - Neuroscience research: neural correlates of fluid analogical reasoning.
   - Possible education application: pedagogies that utilize analogizing to enhance creative thinking in all curriculum areas.
4 Education problem: how to optimize general academic performance.
   - Neuroscience research: neural fractionations of working memory, and neural distribution of long-term memory.
   - Possible education application: redesign of assessment tasks, especially rote recall exams.

Well, that's the ideal. In practice there are any number of limitations and challenges. For one, researchers from different disciplines have their own discipline-centric worldviews, communicated through a specialist lexicon within their discipline. Genuine interdisciplinary endeavour is therefore hard work. My preferred solution here is to use education as the starting point. However, I recognize that it's the neuroscientists who have so far done most of the running – for the obvious reason that they are the researchers, not classroom teachers.

One of the early hopes of cognitive neuroscience in general, and educational neuroscience in particular, was that the results of these investigations might help us to choose between the many 'black box' models of cognition and learning that fill the pages of every textbook on education – at least one per theorist, and several per chapter. As the oft-repeated quip at science conferences goes: 'A theoretical model is like a toothbrush – everyone has one, but no one wants to use anybody else's!' Yet, the plethora of cognitive models can only mean one thing – they cannot all be correct. My bet is that they each contain a glimmer of truth somewhere within, but none are 'correct' as a complete description of how the brain enables thinking and learning. And let's face it, none of those flowcharts of boxes and arrows is ever of any help, or has much meaning, when one is engaged with Year 9 on a Friday afternoon.

Apart from their pragmatic shortcomings, cognitive psychological models reflect a different level of understanding from the neural, so it is important to distinguish these levels when interpreting neuroscientific studies for classroom applications. And most of the classic cognitive learning models, such as those of Piaget, Vygotsky or Bruner, had very little neuroscientific data to inform their construction. But this difference in levels between cognitive and neuroscientific interpretations poses a paradox: the design of any cognitive neuroscientific experiment – typically, taking brain images while subjects undergo some cognitive task, perhaps matching pairs of words or doing arithmetic calculations – implies some *a priori* model of cognition. That is, to test how the brain does anything, neuroscientists must first conjecture at how this is done at a cognitive level in order to devise appropriate experimental stimuli, for example, word pairs that cognitively connect, or arithmetic sums that demonstrate stages of competence. So, we are faced with the paradoxical situation of trying to examine the brain's cognition with tests which we know do not completely reflect how the brain actually functions. It's not as extreme a situation as the A-level English class who discover in their literature paper that they have studied the wrong set text – but there are analogical similarities. This is not to say that brain imaging studies are futile – far from it. The results are usually intriguingly informative, especially if there are significant activations in those areas of the brain hypothesized to be active. But, at the same time, most neuroimaging results are open to alternative interpretations, since we do not yet know precisely what contributions each of those activated areas is making to any particular cognitive task. Furthermore, in any neuroimaging experiment, there are usually additional areas of activation beyond those hypothesized. What can they be up to one wonders?

Education neuroscientific research questions

Whenever educators and neuroscientists gather to discuss educational neuroscience research agendas, there never seems to be any shortage of potentially interesting and relevant research questions. At the National Science Foundation 2007 neuroscience and education workshop mentioned in the Introduction, many complementary approaches and multilevel foci were noted that could be fruitful in addressing a suite of research questions. These included:

- What are the critical developmental links between precursor skills and building expertise?
- How do brain systems build up prior to the emergence of competence?
- What role do basic sensory processing, as well as cross-modal processing, play in learning?
- What are the effects of age on learning, e.g., phonological processing? Is early 'special' and, if so, how and why?
- How do social factors such as socioeconomic status (SES) and home environment make their relative contributions at different points to brain development?
- How does the brain build structured representations? Is bilingualism an informative exemplar?
- What is the nature of complex imagery in informational input and representation?
- What are the neural bases of individual differences in learning and development?
- Can neural correlates be used to measure the effectiveness of different interventions, e.g., symbolic vs. concrete, analogical vs. contextual, naive vs. conceptual?
- What are the roles in learning of components across the whole brain, e.g., amygdala, cerebellum?
- Is core knowledge as designated in national curricula neurally privileged?
- What are the neural signatures of emotional engagement which promote educational achievement?
- What, from a neuroscientific perspective, are the effects of sleep on learning?
- Is there any neural reality to so-called learning styles? And if so, does one teach to a delineated preference or try to enhance a delineated dis-preference?
- Can neuroscience account for expertise and best practice?
- Can neuroscience help explain the big-school–small-school effect whereby best practice in one fails in the other?
- Are there neural switches for establishing secure mentor–student roles? And if so, what supranormal stimuli trigger these switches?
- How do correct concepts supersede or inhibit incorrect naive concepts?

- What are the neural underpinnings of attention: its multidimensionality, informational salience, temporal dynamics in learning situations and developmental trajectories?
- Is there a neural account of attention span?
- Can neuroscience provide a better understanding of memory and knowledge?
- Can neuroscience provide a better understanding of the neural characteristics associated with reward, punishment and motivation?
- What are the roles of mirror neurons in learning by imitation?
- What could be a social neuroscience perspective on the roles of teacher and student?
- What could be a social neuroscience perspective on classroom atmosphere?
- What are the neural markers for teacher–student empathy?
- What types of school learning can be explained by Hebbian models, and which cannot?
- What types of informal learning can be explained by Hebbian models, and which cannot?
- What are the neuropharmacological substrates of working memory?
- What nutritional factors are best to support brain function for learning?
- Are there differentiable and reliable educational endophenotypes?
- Does teaching pupils neuroscience improve their learning outcomes?
- Does teaching teachers about neuroscience improve their students' learning outcomes?
- How do genetic predispositions for neural plasticity interact with learning contexts and social environments?
- What brain systems enable high-value feedback during learning?
- Are there distinct neural correlates of curricula 'tipping points', e.g., fractions in arithmetic?
- How are the brains of high-ability students different from the brains of normal students?

This quest to better understand the brain's learning systems should be particularly informed by neuroscientific accounts of non-normal development such as dyslexia and dyscalculia. Again, there are many potential areas of promising research:

- How do mechanisms of learning contribute, or not, to developmental disabilities?

- How do the brain's multiple learning systems, which operate via different rules, contribute, or not, to learning difficulties?
- How are developmental links altered in disorders of learning such as dyslexia?
- What could be the neural trade-offs for individual pupils, e.g., the mix of 'skill and drill' vs. comprehension tuition required when interventions are delivered?
- Are there specific limits to learning determined by various learning disabilities, e.g., ADHD and working memory capacity?
- Which components of global processing are unaffected by various learning disabilities?
- Are the neural dynamics of competence of children with identified learning disabilities different from those of normal children, e.g., dyslexics who have successfully learned to read?
- Can early neural markers for learning disabilities be identified?
- Can neuroscience provide biomarkers of risk for future learning difficulties?
- How can neuroscience be used to clarify developmental continuums, so that the importance of research on disabilities for understanding typical development is clear?
- What is more effective for brain development, e.g., should educators focus intervention on areas of weakness or strength (or both)? And, if so, in what combination, for which disorder?
- What are the neural effects of stress on learning?
- What neuroscientific data can be gathered to usefully inform reports of learning disabilities in school-age populations?
- What are the contributing neural factors towards resilience to environmental stress?
- What can the brain functioning of children with autism tell us about which brain systems are involved in representing the actions and intentions of others?
- Are there neural markers for children's emotional 'meltdowns'?

Phew! You can certainly rely on academics to generate long lists. But what about research suggestions from school educators? The Oxford Forum asked its teacher members to pose questions which they would like addressed by neuroscientists. Here the generic issue was: 'Many of my students are finding understanding of this or that difficult – what can neuroscience tell me to help me teach them?' Specific teacher questions were grouped under four headings:

1. Cognition of learning (attention, learning, motivation and self-esteem, memory, genetic development):
   - Is ADHD due to a lack of neural connections?

- Is there a negative influence caused by the interference from distracting factors such as noise, movement, etc.?
- What teaching strategies can improve pupils' sustained attention when surrounded by distractions?
- What, if anything, can a classroom teacher do to complement clinical treatments of those pupils with attentional problems which would be classified as developmental disorders, i.e., were a result of neurological deficits?
- What strategies can a classroom teacher employ to improve the attentional abilities of those pupils who have developed bad habits of attention?
- Can pupils keep their concentration better with an explicit understanding of the brain functions involved in keeping and losing concentration?
- Does abstract thinking develop separately within each subject?
- How do adolescent brains develop?
- Are there some developmental disorders which are specific to adolescence?
- What is the neuroscience of dyslexia?
- Why do people learn some things at some times more easily than at others, e.g., pupils in the top science set who cannot write A-level papers, but later in life write articulate research reports?
- Has neuroscience given us a handle which can help teachers select between competing neuroscientific models of learning?
- Why do some pupils learn more easily than others (in certain subjects or across all subjects)?
- Why are there such wide individual differences in perception, e.g., why do less-able pupils have difficulties in interpreting sparse diagrams?
- How is understanding an emergent property of the brain?
- How does experiential learning with external stimuli improve understanding and retention?
- Do successful adult learners make the best teachers?
- Does a pupil's own understanding of brain function influence their ability to learn?
- Can teachers enhance working memory (WM) function, e.g., through training/practice in chunking information?
- Can memory games and mind-mapping help pupils to better organize their thoughts?
- What is the influence of stress on teachers and pupils, and is it a good thing?

- Does teaching emotional literacy enhance children's personal well-being?

2. Environment of learning (sleep, nutrition including water, drugs, physical exercise, lighting, ventilation, noise):
   - Is natural light better for attention and memory?
   - Are there performance-enhancing drugs which are to be recommended?
   - Can recreational or prescription drugs have a detrimental effect?
   - Should pupils/teachers take fish oils?
   - What is the value of tranquillity/calm/reflection upon learning?
   - Can meditation techniques in the classroom improve children's attention through enhanced executive control?
   - What is the importance of good nutrition in cognitive terms?
   - Does exercise enhance cognitive ability?
   - Does this need to happen concurrently with the learning?
   - What about regular, brief, high impact exercise sessions?
   - Is the social environment in which pupils live relevant to their learning, e.g., lack of books in the home, poor role models, lack of parental support?
   - Is there evidence that lack of sleep impairs cognition?
   - Should there be a period of sleep in school? Would this be valuable for all ages?
   - Is the best time for study revision just prior to going to sleep?
   - What are the cognitive effects of drinking water for pupils?
   - Can you teach happiness?

3. Curriculum (literacy, numeracy, science, music, arts, IT/ICT):
   - What are we trying to help pupils to learn?
   - Do we value the academic pursuits above all others when we talk of learning?
   - Should the curriculum be designed around key concepts across different subjects?
   - Are targets a motivating factor or can they be demotivating?
   - Are children's brains different today because of their use of computers and IT?
   - Are there sensitive periods for the acquisition of complex grammar in first and second languages?
   - There is a website that claims that brains can be synchronized to a common frequency, which can then be utilized beneath

music to enhance performance in particular areas. Does this have any scientific credence?
- Do the CASE (Cognitive Acceleration through Science Education) materials and lessons need to be re-interpreted in the light of new neuroscientific evidence for cognitive strategies, such as analogical thinking?
- Are there differences between the brain representations of naive or folk physics, and school physics?

4. School organization (socializing, school hours, timetabling, play, coeducation, early years, gifted and talented):
   - Should quieter pupils who seem to concentrate better on their own be taught separately from the more active, boisterous children?
   - Is grouping pupils by age the best organization for their learning?
   - Do children with learning difficulties have 'bad' bits of their brains?
   - Should we teach to a disability or around it?
   - How does executive control affect delayed gratification?
   - Is there some neuroscience to support the 'big-school–small-school' effect?
   - Are there are 'sensitive periods' in human brain development in which certain skills are learned with greater ease than at other times?
   - What is the neuroscientific account of how gifted and talented pupils learn?
   - How can teachers apply an understanding of gifted students' brain development to develop pedagogic strategies that could be integrated into mixed ability lessons for gifted and talented pupils who suffered lapses in attention due to being unstretched by the work from day to day?
   - What motivates G&T pupils?

Maybe academics aren't the only ones to generate long lists! How much overlap, how much commonality is there between the two lists? It is such a merging of perspectives and aspirations that is contributing to the development of educational neuroscience as an interdisciplinary field of research and application. But the creation of true interdisciplinarity will require translation between the 'two languages, one lexicon' of education and neuroscience. Teachers don't need to be experts in neuroscience, but neither should they be inadvertently misled. Perhaps what is needed is a few interdisciplinary ambassadors to act as translators: a few teachers who change careers to become neuroscientists, and a few neuroscientists who take a couple of years for graduate teacher training and school classroom teaching.

An illustrative example of the need for translation arose at a meeting of the Oxford Forum, during the discussion following a presentation from a professor of pharmacology on neurochemicals, and the possibilities and dangers of smart drugs. The question was, how could drugs such as amphetamines, which usually enhance physical activity, reduce such activity in children with ADHD? The key term was 'inhibition', and its different usages in describing behaviour vs. neuronal interactions. ADHD seems to be the result of an underperforming (relatively immature) part of the brain's prefrontal cortex responsible for executive functioning, whereby the ability to inhibit off-task behaviours is inadequate. At a neuronal level, the inhibiting functionality seems itself to be inhibited. The effect of medications such as Ritalin is to strengthen or enhance this inhibitory functioning.

Similarly, the cognitive neuroscientific and educational data needed to be gathered in order to satisfactorily address many of the research questions posed above will ideally be mutually informative. In particular, longitudinal and large (non-clinical) population studies hold promise for neuroscience data to go beyond the behavioural in addressing educationally relevant questions. Certainly, educational neuroscience would benefit immensely from a large database of neuroscientific information about the typically developing brain. The problem is that no such database exists! But, it could easily be created with international cooperation. Given the thousands of MRI scanners now operating in laboratories and hospitals around the world, if each were to scan, say, 100 subjects in the age range of formal education (5 to 25 years), then combining these data could produce a database of normal brain structures with which to compare the neural effects of particular educational interventions in normal classrooms. This would require international multi-site studies using agreed protocols and multiple measures of brain structure and function, including behavioural measures and SES indicators, and so on. The very large size of the database should control for the multiple variables that we know affect educational outcomes beyond teaching and curriculum. Most education systems administer age-normed tests of literacy and numeracy, (SATS or CATS) together with international comparative tests (e.g., Trends in International Mathematics and Science Study (TIMSS)), and these ready-made large databases of standardized educational achievements could be used for standardized behavioural measures.

As an alternative means to tackling such neuro-epidemiological questions with a realistic sample of students, Czech neuroscientist Tomas Paus provocatively suggests setting up a brain scanner in a school basement.

This way, neuroscientists could image the developing brains of all students in all years as they move through their educational trajectory. Such educational population studies, Paus argues, have good prospects of producing useful information about the complex interactions between neural plasticity within neural development, and formal and incidental learning within institutional settings. To realistically capture such educational complexity, analytic models would have to be dynamic and non-linear in structure, explicitly incorporating feedback as a necessary feature of learning. Obvious ethical and logistic issues notwithstanding, the rationale for such a provocative suggestion is that at present, many of the research questions posed above cannot be addressed, the main reason being the weak mapping between individual variance in brain structure and behaviour due to the unique trajectories of individual neural development. Moreover, genetic data would have to be added to the mix, and the small contributory variance of individual alleles to the multiple genetic bases of educational cognitive behaviours currently imposes another limitation. Consequently, data from a whole-school population over, say, six years, could go a long way towards overcoming this weakness.

Limits to educational neuroscience

Before closing this chapter, we should note, however, that some commentators have argued that the education–neuroscience connection, while well meaning, is basically flawed. Leading American neuroscientist John Bruer, in an article published over ten years ago entitled 'Education and the Brain: A Bridge Too Far', argued that education cannot be directly informed by neuroscience as the former is unable to generalize from detailed specifics of neuronal processes to the behaviours observed in classrooms or with young children's learning. Descriptions of brain function at the cellular level are just too far removed from the behavioural to be of any use at school. Consequently, neuroscience, in its current state, cannot inform education. Bruer noted that experience-dependent neural plasticity is particularly sensitive to environmental complexity, and it occurs throughout the lifetime of the individual. His exemplar of an unsupportable neuroscience–education nexus is that the growth of new neurons in the brains of young animals implies critical periods of educational priming for young children. This critical stage argument proposes that some of the apparently effortless learning of very young children, particularly in learning to speak their native language, is indicative of a window of opportunity which closes with the slowing down of neuronal growth. The difficulty with this line of reasoning, Bruer points out, is that too little is known about the process to be predictive of what stage is attained at what age for any individual child. Rather, the neuroscience–education connection requires the mediation of cognitive science.

I agree that misinterpretations of the science are problematic, perhaps even potentially dangerous, and certainly counterproductive for informed considerations of educational issues. A popular example is the over-simplification of laterality studies, especially of split-brain patients, leading to programmes of left- and right-brain thinking which ignore the important caveat of this research that normally the two cerebral hemispheres are massively interconnected. The point here is that past over-simplifications of some neuroscientific findings do not *a priori* exclude an education–neuroscience nexus. Rather, this compels us to proceed with due caution, as usually exercised in the natural sciences if not in the popular media – especially when it comes to education.

Bruer's other main point was that the conceptual gap between neuroscience and education is too wide to be readily bridged, and so requires the mediation of cognitive science as a half-way point. To me this seems rather an unnecessary distinction – these two disciplines have been married as cognitive neuroscience for several decades. Nevertheless, for many experimental situations it is true that the different levels of description need to be bridged by intermediary levels. To this end, I have proposed a ladder of levels of partial variance in individual differences (Figure 1.1), with descending levels of reduction, and ascending levels of causation from education to brain structure (measurement indicators in parentheses, neuroscience acronyms to be explained later).

But there is nothing to prevent a research project skipping any number of levels depending on the relationship under investigation. For example, within the broad research question: Are there any predictive correlations between differences in brain structure and school outcomes? It is perfectly feasible to seek correlations between aspects of frontal cortical structure such as cortical thickness and educational outcomes across a designated age span (Figure 1.1, dashed arrow). And in fact, this has been done, as reported in Chapter 4. But at the same time, this need not be a one-way street from neuroscience to education. To continue with our example, despite informative psychological models of working memory, we don't fully understand how working memory is fractionated or instantiated at a neural functional level, so to complement neuroimaging investigations into the neural basis of working memory the efficacy of classroom interventions aimed to optimize working memory could be usefully informative.

My difference with Bruer's position is that connections can be made between any of the different levels on the ladder, including directly from neuronal processing to education, as with the many applications of Hebbian learning outlined in the next chapter. It depends critically on the experimental design, and the types of data that emerge. For example,

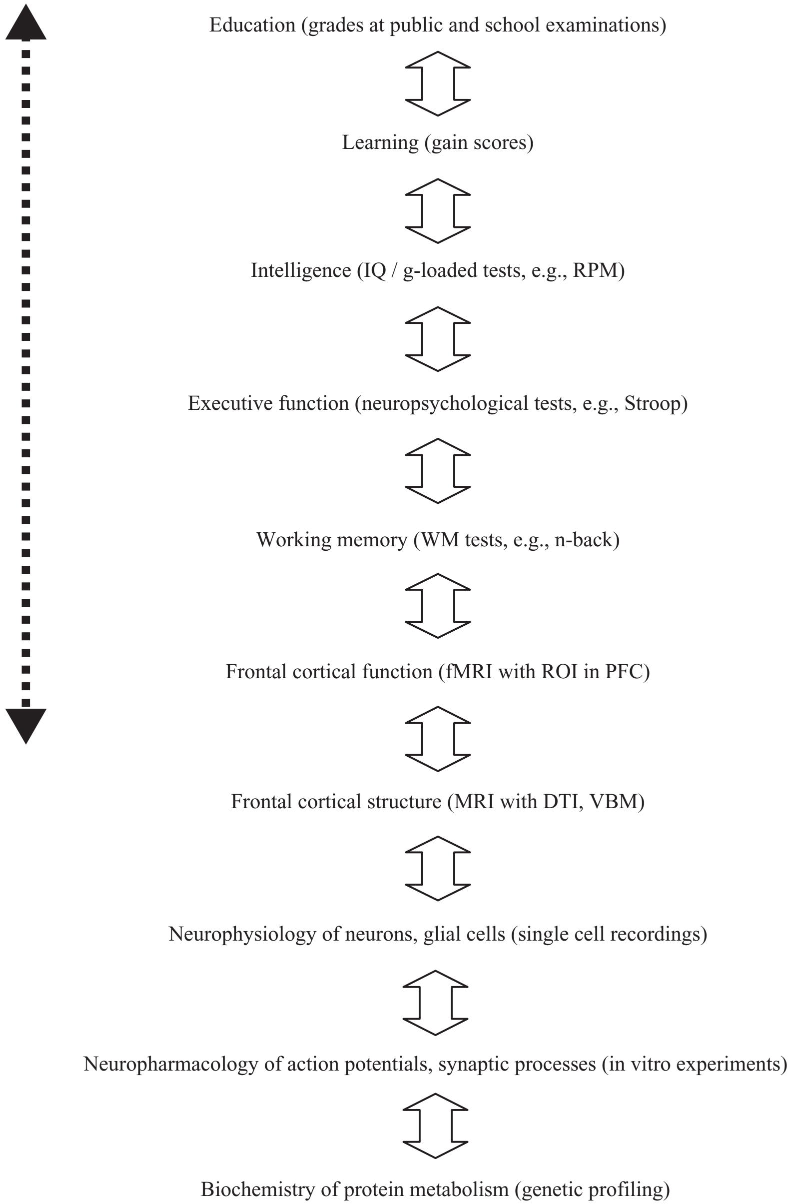

Figure 1.1 Bridges of partial variance between education and scientific descriptions of the brain

rather than the research on critical, or sensitive, learning periods having nothing to say for curriculum design, such research could inform the timing and extent of the use of Vygotsky's Zone of Proximal Development (ZPD) as a pedagogical tool with which to base maximally challenging learning experiences in schools. Moreover, it suggests further research into whether there are critical periods for context-expectant neurological development and parallels for context-dependent neurological development. All of which underscores my argument that educators should be influencing the directions of cognitive neuroscientific research under the rubric of educational neuroscience.

However, I recognize that many educators are persuaded by the argument that the holistic level at which education is conducted is mismatched with the reductionist level at which scientific investigations are undertaken. This is hardly a new argument. Over a century ago, the father of modern psychology, William James, famously said in his *Talks to Teachers*:

> You make a great mistake . . . if you think that psychology, being the science of mind's laws, is something from which you can deduce definite programmes and schemes and methods of instruction for immediate school room use.
>
> Psychology is a science, and teaching is an art.[1]

But James was speaking well before the development of educational psychology, pioneered by Vygotsky and Piaget, as a significant specialization within the psychological mainstream. Similarly, the early criticisms of the ambitions of educational neuroscience were made before the explosion in functional neuroimaging as the major investigative tool in cognitive neuroscience, and its consequent applications to understanding the brain bases of learning. My counterargument to James's is that more relevant and useful professional and classroom applications of educational neuroscience will become available as we gradually come to understand more about brain function through research, which answers educational questions about learning, memory, motivation, and so on.

Nevertheless, it has to be noted, despite neuroscientific and technological advances, scepticism about educational neuroscience has not completely abated, although it has become more diverse. In fact, one could note a rather curious dichotomy. On the one hand, there are those aging education academics who, after a lifetime of not understanding and disparaging all science, see no need to change their ways. On the other hand, there are the 'brain-based' enthusiasts who hope that the current fads of left–right thinking, brain gym, etc., will address the complexities and daily challenges of the mixed ability classroom. One way to portray these various perceptions of neuroscience and education can be to position

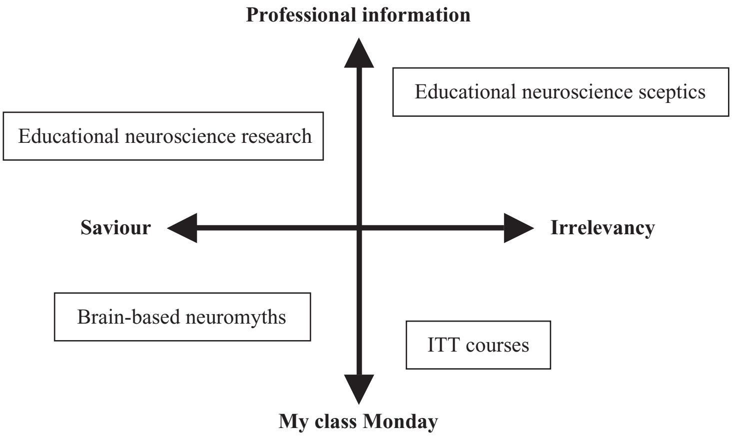

Figure 1.2 Perceptions of educational neuroscience schematic

them along each of two independent conceptual dimensions: a *salience* dimension, ranging from *saviour* to *irrelevancy*, and a *pragmatic* dimension, ranging from *professional background information to my classroom on Monday* (Figure 1.2).

Drawing these dimensions orthogonally to each other produces four quadrants. The top right quadrant, background information but practically irrelevant, represents the position of hardline sceptics. This is in contrast to the so-called brain-based schemes, mostly founded on neuromythologies, in the lower left quadrant representing educational neuroscience as the saving grace of education's future. Initial teacher training (ITT) or pre-service training courses have become increasingly pragmatic in recent years, at the expense, many have argued, of academic background. One might conjecture, therefore, that as ITT courses have yet to encompass educational neuroscience (although sadly in many ITT courses in the UK these neuromyths are taken uncritically as 'gospel'), that teacher training would be positioned in the lower right quadrant, possibly practical but its relevancy as yet unproven. It is my hope that in the years to come, ITT, together with teacher continuing professional development programmes, might move to a more central position in this schematic, where these tensions of theory vs. practice, background vs. lesson plan, might be better balanced. To this end, some American educators have recommended that all future doctoral studies in education should include a coursework component of educational neuroscience.

> Core courses in subjects traditional for education programs, as well as relevant interdisciplinary areas such as neuroscience . . .

> should be required for all entering doctoral students; these courses must be scholarly, rigorous, and intense enough to bear the burden of familiarizing students with the orienting concepts [of] the field, the culture of scientific enquiry, and the special demands of research in education.[2]

But this will come about, I suggest, only if teachers contribute to the educational neuroscience research effort by articulating educational problems and posing possible research questions, and then field-testing the resultant potential applications in their classrooms. Wouldn't we love to know more about questions such as:

- How can we tell if children are learning?
- How can we teach to optimize intelligent creativity?
- Why do individual students learn differently from each other?
- How can we minimize anxiety about school learning?
- Is there a critical period for learning a second language, or music, or physics?
- Should boys and girls be taught separately in some subjects?
- Are the brains of children today different from those of previous eras due to high levels of IT usage?

These are not matters for neuroscientists alone. As much as education can learn from neuroscience, so neuroscience can learn from education, not least by involving teachers in helping to set the educational neuroscience research agenda.

Educational neuroscience questions in a box

Ten years ago, *The Sunday Times* claimed that over 1000 schools in the UK were using 'brain-based' strategies for learning enhancement. Presumably there are more now, as indicated by Sue Pickering and Paul Howard-Jones's survey of UK teachers. This immediately suggests a preliminary programme of research:

- What is the current level of knowledge of cognitive neuroscience in the education community?
- To what extent do school teachers base any of their practice on their understanding of cognitive neuroscience?
- In particular, is there a describable folk psychology of school teachers regarding genetic heritability of intelligence and learning abilities, and genetic correlates with classroom environment?

- To what extent do university educators in teacher preparation programmes incorporate cognitive neuroscience into their courses?
- To what extent do parents expect teachers to employ cognitive neuroscientific evidence-based practice?
- To what extent do students perceive their teachers as being in or out of touch with modern developments in understanding brain function?

Presumably, a large number of schools have been embracing 'brain gym' programmes. Another line of research could be a rigorous evaluation of existing interventions in schools which claim to be based on neuroscientific evidence, e.g., brain gymnastics which purport to increase cerebral blood flow. Would a psychometric analysis of a well-designed (e.g., using matched controls) quasi-experiment find the same level of benefit in school performance that anecdotal reports indicate?