Transforming Learning and the Transmission of Knowledge

PMSEIC

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and the Transmission of Knowledge

Preparing a learning society for the future

Report of the PMSEIC Expert Working Group

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A report for the Prime Minister's Science, Engineering and Innovation Council (PMSEIC)

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Foreword from the Chair

Now is an exciting time to be addressing the issue of transforming learning and the transfer of knowledge due to the many recent breakthroughs in our understanding of the fundamental science of learning, and the ever increasing need to better equip both our young and lifelong learners to address the increasing complexity of a world requiring innovative solutions.

The Transforming Learning and the Transmission of Knowledge Expert Working Group comprised a multidisciplinary group of researchers and educators, creating a powerful intellectual dynamic to address the complexities of learning and learners. As the least expert of this group of experts, it was interesting to watch the group veer away from questions around technology and the massive amount of information available via the internet, to focus on fundamental questions that influence our ability to learn. The multidisciplinary approach, and the involvement of both researchers and practitioners, proposed many innovative solutions that in themselves demonstrated the potential of bringing together such groups to address the science of learning in a more structured and sustained program.

The Expert Working Group came together for only two months, a much shorter time than is usual for PMSEIC working groups, and had, therefore, to limit the scope of what could be covered in that time.

In particular, we recognised the importance of, but were unable to cover in depth, a number of areas including:

- the transmission of knowledge, a topic only briefly touched on in the report owing to its broad nature and rapidly developing Government activity in this sphere;
- ICT infrastructure needs – the potential to use ICT to enhance learning, and the need to support use of ICT by teachers, was considered rather than the physical infrastructure itself;
- early childhood intervention, although it is well understood that there is a strong correlation between educational outcomes and influences in early childhood. Given that it has been some time since there has been a PMSEIC report on this critical subject (i.e. *Developmental Health and Wellbeing: Australia's Future*, PMSEIC June 2001), this may be an area for further work;
- science teaching per se, instead we focussed on learning in general; and
- cognitive issues associated with ageing.

We were, or became, aware of many important and outstanding examples of programs to enhance learning, support teachers and promote learning being conducted by Departments of Education, researchers and other educational groups across Australia, but had insufficient time to complete a full evaluation or stock take of these.

Finally, the practitioners in our group frequently drew us back to the realities of classrooms, the need to address some of the most basic requirements of education (e.g. the lack of trained teachers and even chairs in classrooms in some remote communities), and the need to value and support the teachers who are central to all aspects of formal learning.

I commend this report to the Prime Minister, Cabinet, the Prime Minister's Science, Engineering and Innovation Council (PMSEIC) and the wider Australian community, and in so doing, thank the Expert Working Group for the quality and intensity of their efforts of the past two months.

Margaret Sheil
Chair, PMSEIC Expert Working Group on Transforming Learning and the Transmission of Knowledge

Executive Summary and recommendations

Australia's opportunity to transform learning

Australia is at an exciting point in its history as it develops a knowledge-based learning society. Breakthroughs in our understanding of the fundamental science of learning, encompassing the scientific understanding of how our brains function, our motivations and the practice of teaching, are at a stage at which linking research and practice has the potential to transform how each one of us acquires and retains knowledge throughout our lives.

The outcome of embracing this opportunity at this potent time will be a resilient and adaptive nation, prepared to meet the challenges and opportunities of the future.

Example breakthroughs include understanding the influence of the brain's attention and memory forming processes on learning effectiveness. These can be influenced by personal strategies and instructional design, yielding potential for improving learning capacity. Motivational states which can be adapted also affect learning effectiveness. One such example is the motivational impact of the community and cultural value of learning. By encouraging a culture that supports the value of learning, Australia would increase individual motivation for learning, enhancing each person's capacity for attaining and retaining knowledge.

Australia faces numerous challenges and opportunities that can be met through the development and support of a highly effective and inclusive learning society, including:

- an increasingly complex array of challenges in areas such as the implications of an ageing workforce, environment, immigration, urban development, and sustainable economic growth that require evidence-based responses;
- the need for communities and individuals to adapt quickly and effectively, with input from all stakeholders, to develop innovative solutions to complex issues;
- the continuing gap in educational opportunity for some remote Australian communities;
- the opportunity for Australia to develop sustainable, globally competitive knowledge-based industries underpinned by transformational learning for all, to both cultivate the best and brightest within our population, and to create a broad base of informed citizens who are committed to lifelong learning; and
- the opportunity to place Australia at the forefront of learning sciences and their application, creating significant potential for Australia to grow the GDP contribution of its learning industry, at both a domestic and export level (valued at $12.6 billion in 2006-07 (Reserve Bank of Australia, 2008)).

By building on our current advantages in the area of understanding learning, we can work toward a society capable of meeting the complex challenges facing Australia and other nations, and benefit from the opportunities they present.

The opportunity is now

Now is the time to act. Australia can build on its prominence in neuroscience, breakthroughs in the science of learning, and our experience in managing multi-functional teams to create an inclusive learning society and reap the attendant benefits. With opportunities presented by our proximity and collaboration with countries in the growing Asia–Pacific economy, Australia could maximise these benefits both domestically and through export markets. Action now will help to place Australia in a world-class position in the near future.

Realising these potential benefits will require researchers from the sciences of learning to work with teaching and training practitioners to develop, disseminate and apply evidence-based learning innovations. For all Australians to benefit from this innovative approach will require:

- integration of all appropriate disciplines and professions;
- application and extension of our knowledge of the science of learning;
- involvement of researchers and practitioners to ensure appropriate direction and application; and
- recognition of the importance that such approaches yield benefits for all members of society.

Australia's advantages

Australia has a history of significant advantages on which to build such an approach:

- Our strong history of leadership in neuroscience extends back to Nobel Laureate Sir John Eccles.
- We have well-developed models for cross-disciplinary and inter-professional collaborations between researchers and end users through programs such as the Australian Research Council Centres of Excellence and the Cooperative Research Centres. These collaborations benefit from the relatively small size of the relevant research and professional communities.
- Our assessment of learning in formal educational contexts is recognised globally.
- Researchers are given access to classrooms and universities for assessment purposes, aided by strong Government involvement in education.
- The federal and all state and territory governments have identified the need for better delivery of learning into the future.

This report outlines the current understanding of the science of how people acquire knowledge throughout their lives, identifies potential barriers to knowledge acquisition for all Australians, and presents options for Government consideration that will transform the future of learning in Australia.

Key messages

New knowledge about the brain, cognitive processing and human motivation applied to the subject of how we learn has the potential to drive transformational changes in teaching and learning.

Examples of research advances in these areas include:

- neuroimaging techniques show extensive brain development in later childhood and adolescence in addition to the period of rapid learning in the first three years of life (Lenroot and Giedd, 2006). These later stages of brain development may be associated with learning throughout childhood and adolescence. Learning could be enhanced by better adaption and understanding of these sensitive learning periods at later stages;
- the effectiveness of information processing is strengthened by appropriate early experience. Existing technology assists us to understand how this occurs. By expanding our knowledge we will be able to increase the effectiveness of learning; and
- social and cultural views of learning in communities affect individual motivation for learning. Enhancing these views will better engage communities to encourage life long learning.

Practice and research evidence, however, are frequently disconnected. Innovations are built on the basis of speculation and not properly assessed, and new knowledge with direct implications for practice is often not disseminated to, or applied by, practitioners.

In order to address this, a **unified effort by practitioners and researchers** that advance our knowledge of what education practices work best, underpinned with solid evidence of why they work, should be initiated. Teaching and training practitioners from all areas need to be included in the choice of research direction, and in the application of research outcomes. Practitioner representation should not be constrained to those in formal education settings, but should include a strong representation from formal teachers, parents, industry trainers and coaches, aged carers, community teachers and others.

Learning environments have a significant impact on the effectiveness of learning. Factors such as cultural environment, health, social and physical infrastructure, social skills and family pressure, all aid and/or hinder our ability to learn. These factors are particularly relevant in groups such as disadvantaged youth, Indigenous students and immigrants. Enhanced collaboration between researchers studying the science of learning and practitioners is expected to lead to new ways of addressing persistent educational issues for these groups. This will be achieved through better understanding how environmental factors and disadvantage impact on learning processes to modify or amplify the development of knowledge and skills.

The overall culture and value of learning and teaching also has a significant impact on learning uptake and effectiveness. This can be enhanced by embedding the excitement and value of learning and teaching into the Australian identity.

The role of Information and Communication Technologies (ICT) in learning, both formally and informally, is likely to grow and yet in many cases its effectiveness in enhancing learning is unknown. In addition, variability exists in teachers' familiarity with, and confident use of, ICT resources. Programs to study the effectiveness of existing and new initiatives, along with access to professional development for all teachers in this area, should be initiated in order to address this challenge.

The outcome of these actions will be a smarter, more adaptive and resilient Australia.

Key Recommendations

Urgent challenges exist to ensuring that all Australians are given the opportunity to learn and reach their intellectual potential. Ignoring these will limit Australia's capacity to contribute in a major way to the global knowledge economy.

The Expert Working Group recommends a number of transformational programs be immediately initiated and evaluated, extending from supporting fundamental research into the science of learning and its application to knowledge transmission, through to providing equal opportunity in and access to education in remote locations, valuing teachers and supporting teachers in their use of digital technology.

Recommendation 1

In order to ensure that all Australians are prepared for the future knowledge economy and rapidly increasing complexity of knowledge, we should research, and apply, transformational breakthroughs in the science of learning to develop a resilient and adaptive nation.

The Expert Working Group recommends the establishment of a Science of Learning Program, delivered through a number of interdisciplinary, inter-professional Science of Learning Centres.

These centres would integrate disciplines such as cognitive science, neuroscience, psychology, social science and education, ensure the active inclusion of teaching and training practitioners in setting the research direction, and disseminate and optimally apply research findings. The research would address practical problems that hinder learning, from the basic science of optimising learning through to tackling issues relating to Indigenous learners, learners in regional and remote locations, and learners from underprivileged backgrounds.

The following focus areas for Centres are recommended as a first step:

- Science of Learning Practice – gathering and sharing best practice in learning, researching and disseminating its scientific basis.
- Science of Learning Environment – studying environmental impacts on learning, including the forms and processes of learning in formal and informal settings, and integrating this with an understanding of the basic brain, cognitive and motivational processes that influence learning.
- Science of Learning Process – researching the basic science of learning in areas such as neuroscience, cognitive psychology and motivational theory, and applying these findings to the development of transformational and effective new teaching practices.

Recommendation 2

In some remote Australian communities, school students do not have access to full-time, qualified teachers and adequate resources and facilities (Calma, 2009; Hughes, 2008). Such fundamental deficiencies diminish or prevent positive learning outcomes and reduce the likelihood that students will attend school, let alone finish school and progress to further education.

The Expert Working Group recommends that Australia ensures that all students in remote locations have access to full-time, trained and qualified teachers and quality learning environments.

Recommendation 3

The science of learning tells us that many factors affect an individual's capacity and motivation for learning. These include the social and cultural views of learning in family and community. By creating a national culture supporting the value of learning for all ages, genders and cultures, Australia would increase individual motivation for learning, and enhance each person's capacity for attaining and retaining knowledge.

The Expert Working Group recommends the introduction of a campaign that embeds the excitement of learning, and the value and benefits of acquiring and sharing knowledge, as integral parts of a modern Australian identity.

This campaign would address the need for learning, not merely as a tool for career preparation and progression, but also as a means to become more resilient and adaptable to the changes expected in an increasingly complex world. The program would use science of learning research to inject excitement into the perception of learning. It would debunk 'brain myths', such as the belief that more mature individuals no longer generate new nerve cells in the brain and have reduced capacity for learning, or the belief that we only use 10% of our brain capacity. It would instead be based on the latest research from the emerging field of the science of learning.

Recommendation 4

Studies have shown that outside the students themselves, excellent teaching is the single most powerful influence on student achievement (Hattie, 2003). This importance has not always been clearly articulated to the community, and over recent decades teaching has become a career path that is neither well respected nor well remunerated. In order to maximise their impact, teachers need to have high levels of knowledge in the areas they teach, be at the forefront of research into how to teach, as well as maintain high levels of commitment and emotional engagement.

The Expert Working Group recommends the introduction of a campaign to enhance the status and esteem society holds for its teachers. In addition, it is recommended that remuneration and support for their continuous professional development in both pedagogy and discipline studies would reflect the central importance of teaching in learning and learning in teaching.

This would complement the campaign outlined in *Recommendation 3*. In order to become a society that values learning and knowledge, we need to be a society that values and supports the role of teachers and professional educators in preparing every individual to participate in society.

Recommendation 5

Digital technology adds a new dimension to the learning landscape. The role of ICT in learning, and the number and diversity of technological platforms and applications, is broad and will continue to expand. Currently, the effectiveness of many of these is unknown.

The Expert Working Group recommends a rigorous evaluation of the many widespread applications of digital technology currently employed in learning settings.

This would include applications within a number of sectors such as medicine (for educating patient groups), and commercial computing (such as flight simulation), distance education learning management platforms and the use of open source software to create learning commons. It would enable evidence-based decisions on which are best suited to enhancing learning for all.

Recommendation 6

Studies identify that teachers have several concerns regarding their knowledge and skills to integrate ICT into the curriculum (Hew and Brush, 2007). Considerable variability exists in teachers' familiarity with, and use of, the resources and in their access to professional development in this area (Freebody et al, 2008a).

The Expert Working Group recommends that additional teacher professional development programs be implemented in order to develop the understanding and skills required for the more effective pedagogical integration of digital forms of learning into curricula planning and presentation for teachers, other learning practitioners and students.

1. Introduction

Background

In *Powering Ideas – An Innovation Agenda for the 21st Century*, the Australian Government proposed that the Prime Minister's Science, Engineering and Innovation Council (PMSEIC) adopt a foresight role, scanning the horizon to identify emerging trends over the forthcoming 20-50 years. PMSEIC has implemented this initiative, commissioning several 'foresight clusters' to identify future challenges and opportunities, with Expert Working Groups established to undertake more detailed studies of the identified trends.

The emergence of changing requirements for a skilled workforce was identified as a future challenge and it was proposed that an investigation be undertaken into the potential means of improving the efficacy, efficiency and equitability of learning. This report represents the first detailed Expert Working Group output from the PMSEIC Foresight initiative.

The growing complexity of modern society demands that individuals have ever-increasing knowledge and expertise in order to function as effective members of society. In the past, it was common for students to leave formal education at a relatively young age to enter the workforce, and from there to progress to higher positions by gaining experience and skills through their on-the-job activities.

Presently, the increasing sophistication of equipment and skills that have driven Australia's productivity growth over recent decades has meant that many unskilled and semi-skilled positions have evaporated. This has resulted in higher barriers to workforce entry, and workers entering the workforce today necessarily respond by increasing their years of formal study. Almost 90% of all jobs now require some form of post-school qualification, yet at least half of those in the workforce do not have these qualifications, or have not even completed secondary schooling (Richardson and Tan, 2007). These changes in the workforce will pose a significant challenge to Australia in the coming decades, but preparing approaches to address this now will enhance our ability to thrive.

This report aims to provide options that will ensure that all members of Australian society can acquire the knowledge they need to thrive more rapidly than in the past, even as information continues to expand at an ever-growing pace.

Overview

In the future Australians will need greater technical, social and cultural skills and knowledge, as well as greater personal and interpersonal capabilities, to adapt to changing circumstances. Current practice for learning and knowledge transmission, in an environment of rapidly growing knowledge volume and complexity, will not be adequate to prepare us for this future. This report suggests new, continuously-improving approaches, based on advances in our understanding of the science of learning, to assist the development and maintenance of learning skills for the entire community.

Significant advances have recently been made in our understanding of the psychology of learning, as well as the neuroscience underpinning the mechanisms for learning. Now is the time to utilise these advances. By integrating the appropriate research disciplines, experts and practitioners, we can draw this learning together to drive transformational changes in teaching and learning. Implementation of such advances must be accelerated.

Improved understanding of how people learn can be used to optimise learning environments and methods, maximising the transmission of knowledge. In addition, understanding the brain's management of new challenges will help inform the teaching of problem solving skills. This will be crucial to support Australia's population as it faces increasingly complex challenges in the future.

All human beings learn throughout their lives, with much of this taking place in informal environments before, during and after formal education. Life long learning, especially informal learning, needs to be recognised and nourished to support the goal of a happy, productive and knowledgeable society.

The intention of this report is to:

- outline the current understanding of the neuroscience and psychology of learning over the whole human lifespan;
- identify gaps in our knowledge that should be addressed;
- discuss exciting future scenarios for enhancing learning; and
- recommend immediate actions that will ensure that all Australians are encouraged and given the opportunity to learn and reach their intellectual potential.

Terms of Reference

The Expert Working Group met between early September and mid-November 2009 to prepare the report and a presentation to PMSEIC focusing on transforming learning and the transmission of knowledge.

With a planning horizon of 20 years, the terms of reference were:

1. Identify state-of-the-art understanding of how people acquire knowledge throughout life, in the context of the rapidly developing knowledge base.
2. Identify potential barriers to knowledge acquisition, including environmental factors, and outline the supporting published evidence.
3. Identify and examine Australian and international key case studies to determine the most effective approaches to the acquisition of knowledge.
4. Formulate options for Government consideration that could have a positive transformational impact on the acquisition of knowledge across the full spectrum of socioeconomic environments, including Indigenous, rural and urban Australia.
5. Document the relative contributions of fundamental and applied published research to the findings and identify any key areas for future research.

Approach

The Expert Working Group was chaired by a member of the PMSEIC Standing Committee and included members with expertise in:

- Early childhood development
- Education
- Educational leadership and professional development
- Educational measurement
- Equity
- Neuroscience
- Novel international education systems
- Psychology
- Technology in education
- Workplace/skills training

A list of members of the Expert Working Group is provided at *Appendix A*.

Research Caveats

A new science of learning can be built that links knowledge of the brain to cognition, motivation, behaviour and learning in classrooms and other settings throughout life. These potential linkages, highlighted in the report, are based on neuroimaging and other forms of brain measurement.

Although great advances have been made in learning research from neuroimaging studies, the following issues surrounding the evidence generated by these studies must be considered:

- in order to interpret neuroimages and make a link with learning processes, it is necessary to begin with a well-articulated theory, typically from cognitive science or cognitive psychology;
- it is difficult to interpret images because of the dense interconnectivity of brain structures;
- functional data can only be interpreted in relation to the tasks used to elicit them;
- activation maps are usually constructed using averages that do not display the individual differences that exist in brain function;
- brain function is nonlinear and difficult to interpret; and
- making valid inferences from simple laboratory tasks to the complex social learning contexts of classrooms needs due consideration.

Before the advent of neuroimaging techniques, it was difficult to collect evidence of learning in the general healthy human population. Advances using these techniques have now allowed us to collect this evidence. Even so, most imaging data has been collected from right-handed males in their mid-twenties who are not claustrophobic, and have good eyesight. To date, no single set of developmental learning tasks have been administered to establish baseline measures across the lifespan. Most work of this type has been done with regard to early childhood learning, with less completed during adolescence, and considerably less attention paid to adulthood and old age.

From this it can be seen that drawing inferences about mental activity from brain images, while very powerful, is not straightforward. In addition, considerable gaps in our knowledge exist, gaps that have the potential to significantly improve our understanding of learning in the general healthy population. The need for research in basic neuroscience and cognition will continue alongside the need for implementing current, modern knowledge in the classroom.

2. The Science of Learning Processes

2.1 Learning

Learning is a complex process influenced by a variety of biological, psychological and social factors. Consequently, the investigation of how learning occurs has been tackled from a number of scientific perspectives including neuroscience, cognitive science, educational and social science. This diversity of approaches has increased our understanding of factors that hinder or promote learning. Further progress will depend on integrating these disciplines to develop a common, coherent understanding of how learning operates - a new science of learning.

This section outlines the current knowledge that underpins the new science of learning and highlights the important questions that relate to learning at different stages of life.

2.1.1 The neuronal level

Memory

The ability to learn relies on a permanent record, a memory, being incorporated into our brain for later retrieval. The process of learning, therefore, requires the formation of a memory, its retention and subsequent retrieval. A crucial step in this process is the integration of new memories into the store of existing memories that form our current knowledge.

We are beginning to understand how neuronal circuitry within the brain changes to form the basis of learning. Information entering the brain from sensory sources such as sight, smell, touch and sound results in neuronal activation in various parts of the brain including the hippocampus, amygdala and areas in the cerebral cortex associated with memory formation (*refer Figure 2.1*). Sensory information can be encoded as a memory trace in the connections (synapses) formed within an ensemble of neurons.

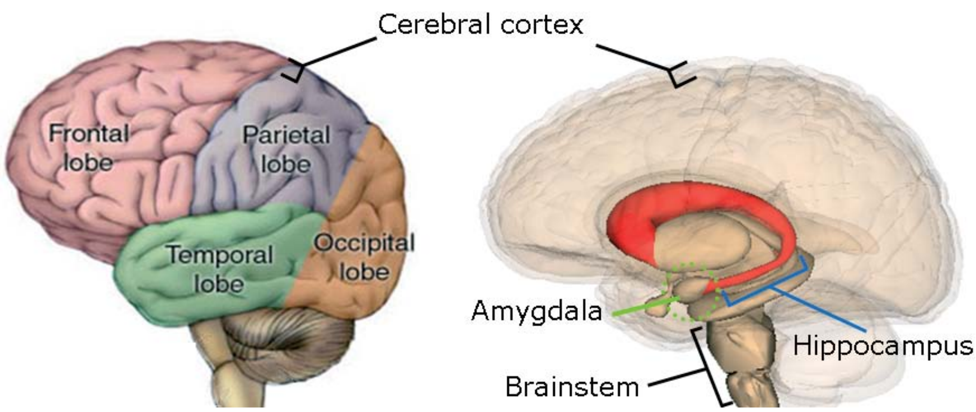

Figure 2.1 Key brain areas (image on right is from Anatomography *maintained by Life Science Databases)*

Key point

Neuroscientists see learning as a process of strengthening and weakening connections between sets of neurons within the brain. This results in a distinct ensemble of neurons more likely to be activated by exposure to identical or similar sensory input. This enhanced tendency towards coordinated activation can be 'stored' for various lengths of time. Replaying events during sleep or rest can strengthen this memory.

The process of changing the strength of connections between neurons in response to environmental stimuli is called synaptic plasticity. It underpins the brain's ability to acquire, store and retrieve information.

Newly formed patterns of coordinated neuronal, and more importantly synaptic, firing in one area of the brain can be consolidated and transferred to other areas of the brain, including the prefrontal cortex where it forms so-called long-term memory.

How this transfer to long-term memory occurs is beginning to be understood. For example, with spatial memory when a rodent navigates through a specific pathway, neurons are activated in the hippocampus. Recent evidence suggests that the activity of these neurons is replayed with a high degree of precision during later periods of sleep or wakeful restfulness, strengthening the synaptic connections (Pastalkova et al, 2008). Furthermore, the replay is simultaneously replicated in the cortex forming a second ensemble of neurons with strong synaptic connections that mirror the connections made in the hippocampus. This becomes the site for long-term memory. Replaying the event or action may be a major learning and memory process. Its occurrence during periods of restfulness highlights the importance of exploring the role played by restful phases in the learning process.

Technical information

The synapse

The connections between neurons occur at the synapse, the gap between neurons across which information is passed by chemical messengers, or neurotransmitters (*Figure 2.2*).

Simple models of learning in animals, like fear conditioning (Pavlovian) and spatial navigation using visual guidance cues, have demonstrated that repeated activation results in a 'priming' of the synapse. The result is that one neuron more easily releases chemicals into the synapse and the chemicals are received more readily by the next neuron due to an increase in molecules capable of binding the released chemical. This process 'strengthens' the connections.

This process of synaptic strengthening can be demonstrated by directly recording from neurons that have been stimulated by electrical impulses upstream (pre-synaptic inputs) to show that they require much less stimulation to fire after exposure to a repeated train of impulses. This is called long-term potentiation, because such changes can remain for extensive periods up to several years or even longer.

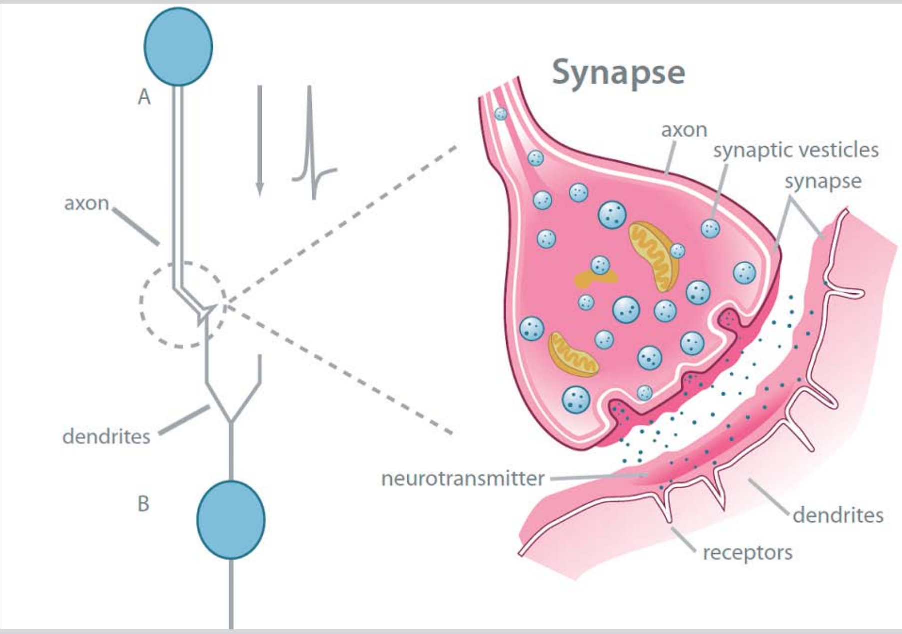

Figure 2.2 Information in a nerve cell flows from the dendrites through the cell body to the axon with information passing from one to another through synapses. Synapses are formed when an axon of one nerve cell (A) interacts with a dendrite of another (B).

Mirror neurons

We are beginning to understand the neuronal basis of how the learning of motor skills and other observable behaviours may be facilitated by observation of others. Recent studies show that when observing the action of another, an ensemble of neurons is activated in the observer (Gallese et al, 1996). The ensemble includes the same population of neurons that would be used if the observer were to carry out the observed action, and are called mirror neurons.

The activity of mirror neurons reflects the observer's recognition of the intent of the action (Fabbri-Destro et al, 2009). They may constitute a vital system used by humans to understand other humans' intentions. It is thought that a defect in this system may underlie autism spectrum disorders. Importantly, it may be a central mechanism that allows the transfer of information in educational and non–educational settings.

Brain imaging techniques

With the advance of non-invasive brain imaging techniques, and their subsequent application to understanding learning, researchers have been able to uncover details of how we learn and which parts of the brain are involved in the process of learning.

Brain imaging techniques have enabled collection of evidence of learning in the general human population. Even so, to date no single set of developmental learning tasks have been administered to establish baseline measures across the lifespan. Most work of this type has been done on early childhood learning, less during adolescence and considerably less throughout adulthood and old age (Geake, 2009; OECD, 2007b).

Details on the different types of brain imaging techniques used to understand learning are provided in *Appendix D*.

2.1.2 Information processing

Psychologists and educators see learning as the product of information processing.

The human brain is a highly efficient information-processing system capable of remarkable feats of learning, memory and reasoning. It has adapted over millennia to decode and interpret new information received via the senses, and to generate strategies for anticipating events and responding to novel events, increasing the adaptive success of humans as a species.

Against this backdrop of evolutionary success, it is important to recognise that the capacity of the brain to process information rapidly and accurately is subject to limitations. By identifying and understanding the limits this places on learning, we can tailor more effective learning environments. As discussed in *Chapter 3,* information processing theories provide a basis for understanding the limits to learning at different stages of development.

Managing information

Key point

From an information processing perspective, learning is the process of 'acquiring new information', with information stored in long-term memory for later retrieval as the outcome of learning (Gazzaniga et al, 2009). Information processing theories of learning have identified three major steps:

- encoding: processing of incoming information for storage;
- storage: a permanent record of encoded information in long-term memory. Here psychologists distinguish two broad types of memory, one that stores factual and autobiographical information (declarative memory), and one that stores a range of different types of knowledge including motor and procedural skills, habits, and conditioned responses (non-declarative memory); and
- retrieval: information stored in long-term memory is activated to generate a representation or to produce a learned behaviour.

Learning requires the coordination of different information processing activities as illustrated in *Figure 2.3*.

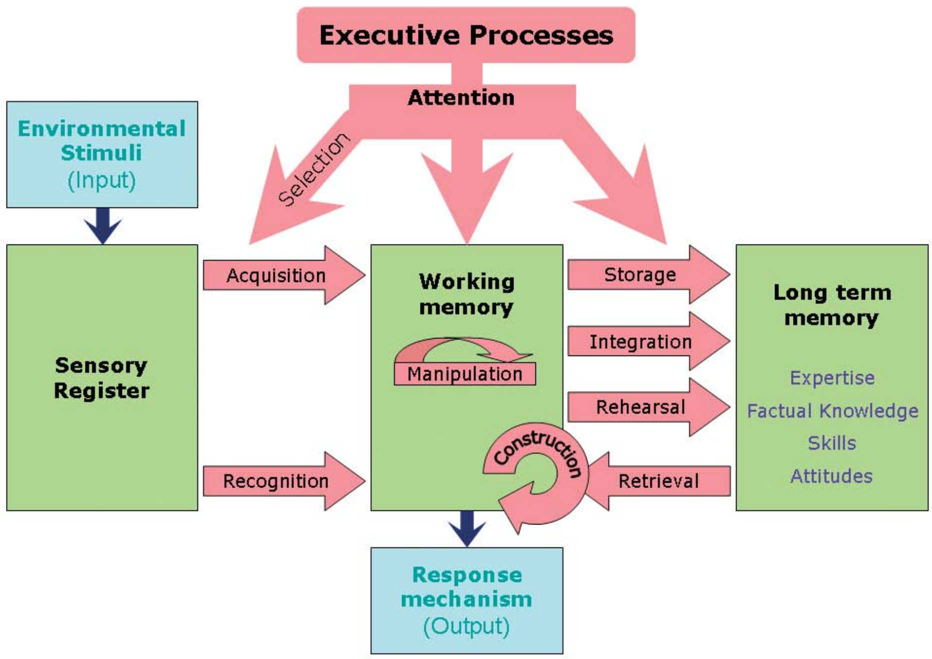

Figure 2.3 Information processing activities important for learning

Encoding, storage and retrieval

In order for learning to occur, information must be 'encoded' into long-term memory storage and later recalled (Sweller, 1988). Encoding is conceptualised as involving four main cognitive processes, illustrated in *Figure 2.3*:

- **selection** is the process of actively paying attention to some information and transferring the selected ideas into short-term memory;
- **acquisition** occurs when material is transferred into working memory for further study;
- **construction** is the active building of connections or links between selected ideas in short-term memory to create a mental model, schemata or framework; and
- **integration** is the construction of links between these new models and prior knowledge in long-term memory.

Key point

Effective learning is considered to require the application of these processes to new information that can then be retrieved as required at a later date from the long-term memory store. The conscious, controlled application of encoding processes to the information to be learned forms the foundation for formal learning that takes place in a variety of educational settings (Weinstein and Mayer, 1986).

Technical Information

Encoding

Key aspects of encoding into declarative memory, essential in formal learning, are:

- information received by the brain is lost within seconds unless selected by attentional mechanisms (300-500 milliseconds for visual sensory memory and about 9-10 seconds for auditory sensory memory);
- selected information moves into working memory where it can be held temporarily or undergo further processing;
- in working memory, information may be processed passively (e.g. rehearsed) or manipulated (e.g. integrated with relevant, existing information stored in long-term memory);
- active processing in working memory is a prerequisite for storage into an enduring or 'long-term' memory store; and
- information can be 'retrieved' at a later date from the long-term memory store to create a conscious representation that can then be applied to answer questions, solve problems or otherwise guide behaviour.

Non-declarative memories:

- are sometimes neither intentional nor subject to conscious control; and
- emerge over time as we gradually extract and consolidate the elements shared by repeated experiences and proceduralise knowledge (Squire, 2004).

Unconscious non-declarative memory processes form the foundation for the informal learning that takes place spontaneously in most settings, regardless of their educational intent. The content of informal learning is not always conducive to reaching the learning goals formal educational settings are intended to reach.

Declarative and non-declarative memory work in concert to determine what we learn, how we learn it, and how we feel about the learning process. Declarative memory refers primarily to what we learn, non-declarative memory refers primarily to how we learn and how we feel about the learning process. When informal learning conflict with formal learning goals, learning is likely to be less effective.

Working memory

Cognitive theories of learning and memory have provided the basis for understanding how children learn best in schools. Educational theories have focused in particular on the encoding stage, where incoming information is processed for storage, and specifically on the working memory processes that facilitate learning.

Working memory has limited capacity and time to process novel information, while long-term memory is thought to have virtually unlimited capacity. Working memory limitations act as a bottleneck when it comes to learning. Critical to improving the learning of complex knowledge and skills is the learner's development of strategies that enhance encoding, in particular working memory processes. The effectiveness of encoding can be influenced through instructional design and technology as discussed in *Chapter 3*.

Strategies that enhance the efficiency of working memory include:

- chunking information, that is linking several items of information with knowledge already stored in long-term memory;
- the use of metacognition, our understanding of how we learn, to enhance the efficiency of working memory; and
- repetition of procedures until they become automated, and make fewer demands on memory resources (Gupt and Cohen, 2002).

These basic facts about the cognitive architecture of humans have important and widespread implications for the design of curricula, the structure of learning environments and teaching practices (Sweller, 1988; van Merriënboer and Sweller, 2005). Instructional designs that carefully build on existing knowledge, and reinforce that knowledge through repetition, serve to maximise the effectiveness of working memory and encoding. This frees working memory resources so they can be used for other purposes, such as the deep elaboration that leads to insight and the gaining of deep knowledge.

Deliberate practice

The gaining of deep knowledge can be enhanced by analysing what we are learning while we are learning. This is known as deliberate practice and involves evaluating progress, responding to feedback, and predicting and planning subsequent performance. Studies of differences between experts and novices across a range of fields have revealed that the amount and diversity of deliberate practice is the most important determinant for expert levels of performance (Ericsson et al, 1993; Wood et al, 2009).

Individuals who engage in this deliberate practice learn more about tasks because they extract more insight from their experience, and they delay the point at which they stop thinking about how to do a task. A common example is the use of software programs such as Excel, which individuals explore and consciously analyse only up to the point that they are able to complete the immediate tasks before them. This typically means that they end up learning less than 10% of the program's functionality.

Development of skills in the evaluation, diagnoses and planning of judgements required for deliberate practice contribute to the learning of knowledge (Ericsson et al, 1993). However, for individuals who lack the required basic skills, the conscious processing effort required for deliberate practice on many learning tasks, particularly those that are more difficult to learn and require overcoming setbacks and coping with failure, is overwhelming or too frustrating. This is true for adults as well as children (Wood et al, 2009).

Training in deliberative processing skills and other encoding strategies, supported by the use of technology and tools, may enhance learning and help to remove the differences that emerge when students are at different starting points in the learning process. As discussed in *Chapter 3*, development of these skills is particularly important in supporting the methods by which adults learn.

The role of attention

Key point

Mechanisms of attention are essential for virtually all aspects of learning and memory (refer to *Figure 2.3)*. At each stage of learning, attention processes are crucial in allocating the brain's resources within and between tasks, and to other aspects related to the control of thought and behaviour (White et al, 2009; Anderson et al, 2001).

Attention helps us to focus our mind on the task at hand. Attentional processes provide a means for the brain to prioritise those aspects of the sensory environment or task that are important for ongoing behaviour. These same attentional processes also act to suppress or 'tune out' sensory stimuli and distracting thoughts that are currently irrelevant for the task at hand. Without attention all information received by the brain would be processed with equal priority leading to 'information overload'.

Technical information

Attention and the brain

Recent human brain imaging research shows that selective attention is controlled by a distributed network of brain areas that control different aspects of information prioritisation such as the ability to:

- filter sensory information (parietal lobe);
- think flexibly, reason and plan for the future (frontal lobe);
- learn new rules and implement them in the service of adaptive behaviour (prefrontal cortex); and
- provide bottom-up 'drive' to sustain attention (cortical and brainstem regions).

Further information is provided in *Appendix D*.

For learning to take place effectively, it is essential that attention processes are sustained over extended periods. Brain processes responsible for sustaining attention can remain effective for 30-45 minutes, but become markedly less efficient thereafter, and cannot be re-established without a break or a change in task demands. Sustained attention, also known as vigilance, is critical for effective learning (Warm, 1984).

2.2 Development

The processes that underpin learning in infants, children and adults are much more similar than was once thought. The seemingly illogical thinking of infants and young children, well known from the work of Jean Piaget (Piaget, 1954), is now interpreted as reflecting the limitations of their ability to process information, and their limited knowledge base.

Learning mechanisms themselves are actually rather similar throughout life. The mechanisms emerge early in childhood and are then refined over the course of life. The learning and thinking skills of an adult are the end products of a developmental process beginning before birth.

In this section, we further sketch the development of learning and identify issues that can act as barriers to learning over the course of a life time. A summary of these factors is presented in *Appendix E*.

Key point

Educational research suggests five factors shape learning at all ages:

- the maturational status of brain structures and processes that constrain information processing;
- the efficiency of the information processes required for learning;
- the extent of the knowledge base of the individual;
- the motivation of the individual to learn; and
- the extent to which the environment supports learning (*see Chapter 3*).

These factors change systematically throughout childhood and adolescence and less consistently into adulthood. Their impact on learning is discussed in the following sections.

Basic learning mechanisms, abilities that allow the individual to learn, are now thought to be in place at, or within a few months of, birth (Goswami, 2008). These include the ability to detect associations between objects and events, to extract common elements or features shared by different objects and events, to learn conditional probabilities, to connect causes and effects, and to use analogies. Nurturing these abilities from the earliest stages of childhood is critical to the development of the motivations and capabilities for lifelong learning that will determine happiness, success and contribution to society.

2.2.1 Brain structures and processes

Research on infant learning has provided impressive evidence that, from approximately three months of age, infants apply learning mechanisms in a similar fashion to adults to learn about their world (Spelke, 1994; Baillargeon, 2004).

Key point

At every age, the maturational status of brain structures and processes constrains the information processing that underpins learning. At birth, the major structures of the brain are already in place. Rudimentary connections between neurons have been generated. As the brain matures, these connections are further developed, leading to greater capacity to embed learning.

Early in life, infants' cognitive processing skills are limited by the lack of neuronal connections (OECD, 2007b). The majority of neuronal connections are generated after birth. A key part of development involves a streamlining process, in which connections that are frequently activated by sensory input are strengthened, while infrequently activated connections are pruned (Blakemore and Frith, 2005). Experience and biology interact creating, and then streamlining and finetuning, connections between neurons to form 'information highways through the brain' which respond efficiently to the environmental stimuli to which infants and young children are most frequently exposed.

Initial connections between neurons are formed in genetically programmed waves that occur at different ages in different areas of the brain, depending on the complexity of the information processing with which an area is involved. In areas involved in more complex information processing such as those involved in self-regulation, synapse formation peaks later.

The timing of each wave, and the areas of the brain in which it occurs, are set out in *Figure 2.4*.

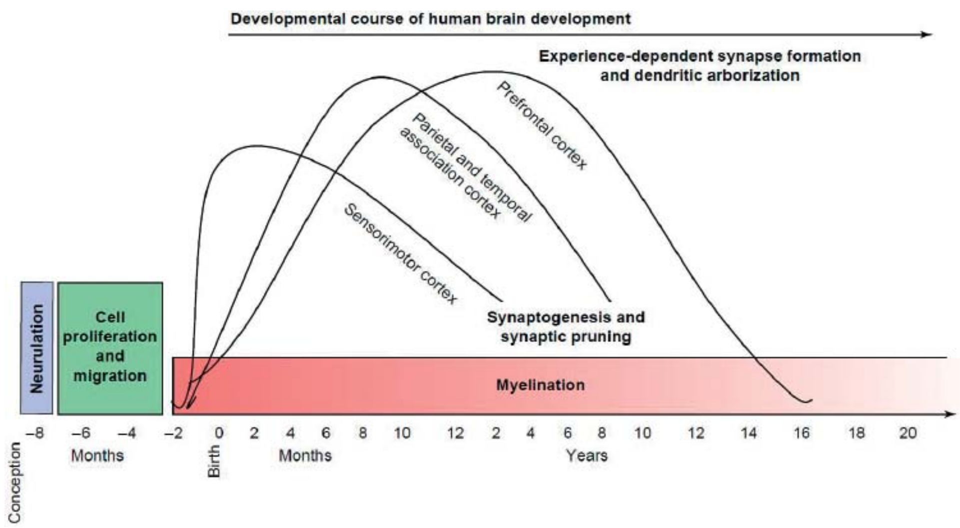

Figure 2.4 Synaptogenesis (synapse formation) in the brain as a function of age. There are three distinct waves of this occurring in different areas of the brain. [1]

[1] Reprinted from *Trends in Cognitive Sciences*, 2005 9(3) Casey, B.J., Tottenham, N., Liston, C. and Durston, S. *Imaging the developing brain: what have we learned about cognitive development?*, 104-110 (2005), with permission from Elsevier.

Key point

Are there periods in which the brain is particularly suited to learn?

Newly generated neurons are preferentially involved in learning and memory formation as they are more easily activated. This early period of easy activation has traditionally been thought to represent a sensitive period in which the ability to learn is enhanced. If missed, particular forms of learning may never occur adequately. The absence of sensory stimulation may form an obstacle to this vital aspect of early development (Blakemore and Frith, 2005). Exposure of an infant to a diverse, enriched environment is essential for the development of the neural pathways required for lifelong learning.

While the first three years of life are a period of particularly rapid learning, the recent application of neuroimaging techniques has shown extensive brain development in later childhood and adolescence (Lenroot and Giedd, 2006) (*Figure 2.5 refers*). This newly recognised burst of reorganisation in the brain raises the possibility that there are sensitive periods in later childhood and adolescence, focused perhaps on streamlining brain connectivity under the influence of culturally-based knowledge (Blakemore and Frith, 2005).

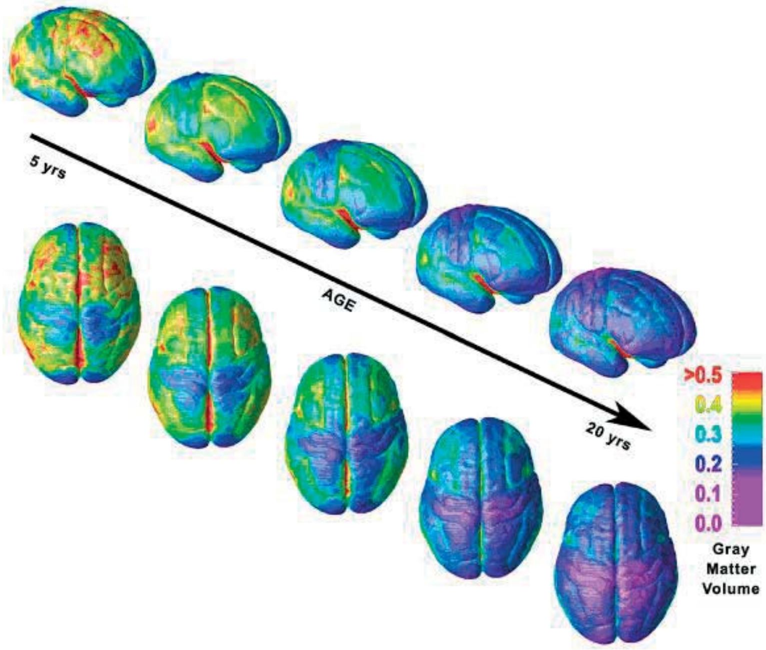

Figure 2.5 The changes in grey matter in the brain as a function of age between 5-20 years of age. Grey matter volume follows an 'inverted U' developmental course with volumes peaking then waning at different times in different areas as the brain matures and neural connections are pruned. [2]

The adult and ageing brain

In recent years, investigations into the development of the brain have extended beyond childhood and adolescence. These show that while the early, genetically-programmed synapse formation provides the basis for common brain functions, synapse formation continues throughout life. In response to individual experiences, new synapses are generated to strengthen and elaborate neural circuits that underlie aspects of our functioning and individuality (Greenough et al, 1999). This synaptic plasticity is the basis for adult learning.

Modern stereology has demonstrated that the aged brain contains a full complement of neurons and their processes (Burke and Barnes, 2006). This challenges one of the most prevalent and resilient myths about the brain that the brain declines in function through progressive loss of neurons and shrinkage of its processes (*refer to Information Box 1*). More evidence against this myth comes from a surprising, recent discovery that some brain areas associated with learning and memory, for example the hippocampus, produce neurons throughout life.

However, the overall production of new neurons declines rapidly with age in animals (Kuhn et al, 1996) and Magnetic Resonance Imaging (MRI) studies suggest that this correlates with some decrease in hippocampal volume in aged humans (Valenzuela et al, 2008). There is also evidence that synaptic plasticity and the speed of nerve impulses declines in ageing brains (Foster and Norris, 1997). In particular, there is rapid decline with age in neuronal production in the hippocampus

2 Reprinted from *Neuroscience and Biobehavioral Reviews* Vol 30(6), Lenroot RK, Giedd JN. *Brain development in children and adolescents: insights from anatomical magnetic resonance imaging*, 718-29, (2006), with permission from Elsevier.

(Walker et al, 2008). These new neurons that are produced are thought to preferentially encode spatial learning and memory (Ge et al, 2008). Their decline may explain the decline in memory of time and place and the reduced ability to navigate in the aged (van Praag et al, 2005).

Serious conditions of neurological decline are predicted to increase as the Australian population ages. The World Alzheimer Report (ADI, 2009) projects dementia will nearly double every 20 years, and a 2009 Access Economics report predicts a four-fold jump in Australian dementia patients from 45,400 in 2009 to 1.13 million by 2050 (Access Economics, 2009). By the 2060s, expenditure on managing dementia is expected to outstrip all other disease conditions. Determining how to prevent or limit mental decline in the ageing population would have significant benefits.

Maintaining and boosting synaptic plasticity and neuronal production are two promising avenues for ameliorating mental decline. In particular, the impact of changes in new neuronal production has been demonstrated through animal studies. Prevention of neuronal production in adult animals leads to an inability to learn certain navigation tasks, and inhibits long-term memory formation. Conversely, spatial learning is improved in older animals by promoting an increase in neuron production through physical exercise or introducing them to an 'enriched' environment.

Key point

Studies have shown that people who lead an active and exploratory life show maintenance of an area of the brain, the hippocampus, important for learning and memory. Lifestyle changes may be used in the future to enhance learning and memory.

Information Box 1

Brain myths

The lack of dissemination of rigorous scientific information about how the brain functions, learns and ages has led to a number of erroneous beliefs, that still persist today:

'No new nerve cells can be made in the brain after birth, certainly not in the mature or older person'

Although the number of nerve cells is largely complete by the first few years of life, it is now clear that new nerve cells are made throughout life in regions of the brain associated with learning and memory. Recent evidence suggests that these new nerve cells are vital for some types of learning.

'The brain of aged humans is characterised by loss of a large number of nerve cells'

While some degenerative diseases like Parkinson's and Alzheimer's do lead to loss of nerve cells, the brains of most older people contain virtually the same number of neurons as that found in a young adult.

'There are critical periods when certain learning must occur'

There are periods when learning skills like language are 'easier'. However, this is by no means absolute because the synaptic plasticity that underlies language acquisition is extant even in old age.

'We only use 10% of our brain capacity'

The use of functional imaging, that uses blood flow as an indicator of brain activity, has shown that all portions of the brain are used at some stage.

'The left and right side of the brain act independently'

The hemispheres are connected by a superhighway of fibre connections. In fact, half the nerve processes leaving one hemisphere end-up connecting to the other side. The brain is highly integrated. While some functions, like language, may predominately reside in one hemisphere, their regulation is dependent on inputs from both sides.

'Men and women have different types of brains'

While sex hormones do affect certain characteristics, like size and certain numbers of types of nerve cells, there are no studies that show any basic differences in the mechanisms underlying learning and memory.

'You can learn in your sleep'

This may be half-true. While learning of new material probably doesn't occur in sleep, it is becoming clear that periods of sleep or restfulness may be required for the consolidation of memory by replaying previous episodes in various parts of the brain.

However, the old adage, **'Use it or Lose it'**, appears to be largely correct. The synapses that store memory are dependent on constant reinforcement, so continually providing stimuli through exploration or gaining new knowledge appears to be vital for retention of maximal function.

2.2.2 Learning mechanisms

The level of development in higher order information processing systems constrains learning mechanisms, extending or limiting their efficiency in acquiring new knowledge.

Brain development occurring during gestation equips infants to carry out primitive information processing from the moment of birth. Focused visual attention has been demonstrated in infants just a few days old (Slater, 1989). Memory is functioning even before birth. For example, there is evidence of learning of auditory stimuli to which the infant has been exposed prenatally (e.g. recognition of the theme song from 'Neighbours', the mother's voice) (Hepper, 1997).

The information processing systems that underpin learning (perception, attention, memory, executive functions) are complex systems mediated by different areas of the brain. Information processing in these systems is initially primitive. As the brain matures component subsystems first develop, and are then integrated into a single, efficient functioning system.

The speed and capacity of information processing in these systems also increases as neural networks are streamlined by experience, and communication between individual neurons becomes more rapid with the myelination (insulation) of the axons along which electrical impulses travel. By approximately 15 years of age, the speed of information processing is equivalent to that of adults (Hale, 1990). Increases in processing speed that occur during childhood are linked to improvements in performance on a range of cognitive tasks (Rodrigue et al, 2005).

2.2.3 Attention

Key point

Efficient learning requires strategic control over attention. Attention must be focused selectively on stimuli and mental operations that are relevant to the task at hand. Responses to distractors, which are unavoidable in any real life situation, must be inhibited. The focus of attention must be sustained long enough to complete the processing required for the task at hand, then switched smoothly to new stimuli and operations.

As the development of strategic control subsystems proceeds, children become more able to exercise the control of attention required for efficient learning (Posner and Rothbart, 2005). Attentional processing changes markedly as different subsystems mature. Early attention is reflexive, being dominated by environmental stimuli. A sudden noise or change occurring in the periphery of the visual field will elicit an automatic shift of attention. Reflexive attention subsystems are mediated by early maturing brain areas and so become active within a few months of birth (Ruff and Rothbart, 1996). Strategic or executive subsystems become active several months later.

Strategic control over attention increases in strength as the subsystems of the brain mediating executive functions mature throughout childhood (Anderson et al, 2001; Manly et al, 2001). Selective attention improves as the pull of irrelevant information can be inhibited. Sustained attention improves as mental effort can be applied to hold attention at a selected focus for longer periods. The flexible deployment of attention improves as attention can switch more rapidly and accurately between mental operations (Anderson et al, 2001; Manly et al, 2001).

The processes that allow children to regulate attention contribute to their ability to regulate their own behaviour. Importantly, the ability to delay gratification at preschool age, for example to wait before enjoying a cookie or marshmallow, is significantly associated with both parental assessments of executive functioning and scores on the SAT exam in adolescence (Sethi et al, 2000). Self-regulatory skills in early childhood provide information about strategic functioning several years later.

2.2.4 Memory

The encoding and consolidation of information stored in memory becomes more robust with development. This in turn enhances the ability to retrieve and apply information where appropriate. For example, the capacity of working memory for a string of digits presented aurally is four digits in 5 and 6 year-olds. In 13 year-olds, it is six to seven digits, close to the adult memory span of seven digits (Anderson et al, 2001).

Key point

Increases in the capacity and mechanisms of working memory are particularly important for learning. They allow the child to hold more chunks of information in mind while they manipulate them, allowing deeper and more elaborate processing as more ideas or concepts can be manipulated simultaneously (Halford et al, 2007).

An example of the consequences of the weaker memory traces present during childhood may be infantile amnesia, the inability of adults to remember the earliest years of their childhood. One explanation of this is that the memory traces that link events in the young child are too weak for the events to be remembered later as part of an adult's autobiographical memory (Goswami, 2008).

The stabilisation of working memory function, beyond approximately 14 years of age, means that development beyond that point is driven mainly by the expansion of knowledge, procedural skills and metacognition. This development will be a product of the diversity and nature of learning opportunities that the individual encounters through formal education and life experiences. The development of encoding skills and attitudes that affect the individual's motivation will influence their ability to take advantage of those opportunities. Inequalities in the development of personal capabilities and learning opportunities can set developmental trajectories where, in terms of learning, 'the rich get richer and the poor get poorer'.

2.2.5 Knowledge

Learning is constrained not only by the developmental status of information processing, but also by the extent and nature of existing knowledge. Existing knowledge provides the basis on which new learning builds, and also helps determine where to focus attention when encountering new information (Goswami, 2009).

Primitive, or naïve, knowledge of fundamental aspects of physics, biology, and numeracy has been demonstrated within the first six months of life (Goswami, 2009). Such knowledge provides an initial, rudimentary framework within which learning mechanisms can operate to build up steadily more sophisticated knowledge from the information. Infants seem to be born with the propensity to attend to novel or unexpected aspects of their environment that are inconsistent with their existing knowledge. This has the effect of focusing attention on aspects of the environment from which they can learn.

Key point

Repeated exposure to a variety of experiences is the basis for the development of conceptual knowledge.

The infant or young child forms rudimentary representations of concepts by extracting features shared by repeatedly experienced events and objects. Exposure to similar objects and events in different contexts allows the concept to be elaborated.

In adults, teaching of abstract concepts and frameworks for later application in problem solving across different tasks and contexts is more effective when multiple and diverse examples are used (Gentner et al, 2003). The use of multiple examples parallels the diversity of experience that influences concept learning in children, and the development of expertise across a lifetime (Ericsson et al, 1993).

We now know that young children are capable of constructing more sophisticated understandings of the world around them than was once thought to be the case. When they start kindergarten or school they need to connect what they are seeing and hearing to what they already know.

This is a reminder that learning in educational settings is rarely a matter of adding knowledge to 'empty vessels'. As emphasised in *Chapter 3,* learning at all stages of life is about building new personal knowledge and understandings on to existing knowledge and beliefs.

Beyond the age of 14, working memory capacity and other cognitive abilities are generally believed to stabilise. Knowledge in long-term memory continues to grow and becomes increasingly more influential as a predictor of performance and achievements in work and personal life (Ackerman, 1996), as illustrated in *Figure 2.3*.

Lifelong learning includes the continual development of knowledge in long-term memory and requires the motivation to undertake a diversity of tasks and challenges. It is also enhanced by utilising deliberative processing skills for effective reflection and learning from experience. Equating the capability for learning to the development of knowledge in long-term memory, and not to traditional measures of intelligence (e.g. IQ Tests), has important implications for all forms of learning.

Children's knowledge about their own thinking and learning, their metacognition, is very limited in preschoolers, but begins to develop in middle childhood (White et al, 2009; Hoffnung et al, 2009). The development of metacognition, in combination with control over information processing, allows the strategic use of the brain's resources contributing to increased efficiency in learning in later childhood and adolescence.

2.2.6 Motivation

Learning requires the active and sustained involvement of the learner with the information that is to be learned. The learning of more advanced forms of knowledge and skills will typically require persistence through setbacks, failures and substandard performance, interspersed with gains that indicate a growing mastery. Notably, learning can occur through activities that do not have learning as their deliberate goal. In fact, the phenomenal burst of learning in the first few years of life are the result of the infant's natural curiosity (Hoffnung et al, 2009).

Even very young infants develop expectations about the consequences of their actions. Once they become able to act intentionally on their environment, the consequences of their behaviour have an emotional impact. Infants frown when an action doesn't produce the expected result, and smile when it does (Harwood et al, 2008). A sense of 'competence' is being built up. The infant's pleasure in mastering some aspect of their world is thought to be a primary motivation for infants to engage in learning-oriented behaviours that teach them key information about people and objects in their environment (White, 1963).

Like infants, young children are spontaneous, active learners, driven by the desire to solve problems and reach new goals (e.g. how do I get to that interesting looking object?). They are constantly applying and extending their knowledge in a way that is meaningful for them in the process of negotiating their environment.

When children begin school, they are confronted with a different approach to learning (Hoffnung et al, 2009). Learning is formalised. Society prescribes what is to be learned, how it is to be learned, and how the products of learning are to be evaluated. Not surprisingly, children's motivation to learn often changes as they progress through primary school.

Once in school, the mix of internal and external forces that determine a student's motivation for learning will vary. However, the psychological states are the same as those that determine motivational learning throughout life (Bandura, 1986).

Across children and adult samples from a wide range of cultures, the following psychological states have been found to have the greatest impact on learning:

- clarity of goals and expectations that the individual is committed to achieving (Locke and Latham, 1990). Commitment to learning goals is influenced by how challenging and achievable they are seen to be;
- self-efficacy or the individual's belief in their capability to master a task with the available resources, including their own knowledge and skills and support from teachers and others (Bandura, 1997). Students who doubt their capacity to learn will often lose their commitment to learning and withdraw physically or mentally. Those who are committed to learning, but lack self-efficacy, are more likely to suffer stress or anxiety reactions to learning that can further undermine their learning;
- a positive valuation of the task of learning or the outcomes to be achieved from learning. This may come from mastery of a task that one values and wants to do well, the desire to learn for learning's sake, or externally administered rewards, such as grades, promotions or approval of others (Hoffnung et al, 2009);
- a belief that ability is developed and not innate (Dweck, 2000; 2006). Individuals who believe that abilities are innate are more likely to interpret setbacks and failure as evidence of a lack of ability. Individuals with a growth mindset for learning believe ability is a reflection of strategies and effort and are more resilient and more adaptive in their learning (Dweck, 2006). Supportive and structured learning environments that ensure progressive mastery can diminish the negative impacts of fixed mindsets about ability; and
- a personal identity that includes learning and mastery as important personal attributes.

Key point

Most children begin school with positive attitudes to learning that act as a powerful internal motivation to learn (Perry et al, 2001). As they become aware that their learning is being evaluated by comparing them with their age-mates external motivation becomes increasingly important, as discussed in *Chapter 3* (Harter, 1996).

The clarity of an individual's goals and expectations, self-efficacy beliefs, positive valuing of learning, incremental view of ability and strong personal identity as a learner, impact positively on success.

2.2.7 The environment

At every stage of life environmental factors affect the quality of learning. Before birth the quality of the intra-uterine environment affects brain development. After birth, the streamlining of the brain to form the pathways that mediate information processing and the accumulation of early knowledge, require a rich and varied range of information from the environment (Blakemore and Frith, 2005). How limitations in the environment of the child can hinder development is discussed in *Chapter 3*.

Attempts to remediate learning problems are as old as the learning problems themselves but have had mixed success for some populations of students. A recently developed instructional program targeted the difficulty that children with reading disabilities experience in processing speech sounds (Shaywitz et al, 2008). Children with reading disabilities in the second and third grades of an American school received intensive practice in the sound-symbol associations that underlie written language in daily, one-on-one tutoring sessions. The children's ability to read improved and Functional Magnetic Resonance Imaging (fMRI) before, immediately after and one year after intervention showed the behavioural improvement was accompanied by increased and lasting development of the neural systems involved in reading.

A second program was directed specifically at the enhancement of executive and working memory in typically developing children. The researchers found that game-like exercises, 'played' over a five-day period, successfully trained executive attention and working memory in typically developing four year-olds (Posner and Rothbart, 2005). At the end of the training, executive functioning and attention control had improved, with EEG measures of brain activity showing patterns of brain activity in areas that mediate executive attention more closely resembling those of adults.

Key point

Impressive evidence of the importance of environment is provided by the effects of intensive 'training' in more natural circumstances. Children raised in bilingual environments show superior performance on a range of measures of executive control from an early age. Importantly, the advantages of regularly using more than one language are not restricted to childhood. Lifelong bilingualism has been found to delay the onset of dementia (Bialystok and DePape, 2009). Children who take their study of music to a high level show similarly superior performance on measures of executive control.

The mechanisms underlying the effects of bilingualism and music are not, as yet, clear. One criterion for their occurrence is thought to be extensive practice. The high level of engagement of the learner may be a second factor.

The higher-order information processing mechanisms that benefit from these experiences can be expected to contribute substantially to the individual's ability to work effectively with the burgeoning knowledge base of the future. We need to explore the learning potential of everyday activities in which individuals of all ages engage spontaneously and with high levels of engagement.

Gaps in research

Whilst advances have been made in understanding the science of learning, further research is required in order to fill crucial gaps in knowledge. Example research areas include:

1. Neurons of all ages retain the ability to undergo synaptic plasticity. Determining how one can boost this process will have enormous implications for how we manage an ageing population and prevent cognitive decline in addition to its importance to learning at all ages.
2. Developing environments and activities that promote higher order information processing would be a major adjunct to improving the learning capabilities of people of all ages.
3. Exploring the importance of interspersing restful phases during the learning process could lead to an evidence-based approach to incorporating this into teaching practice.
4. Knowledge from neuroscience and cognitive psychology studies of attention could be used to design techniques and tools for the development of selective and sustained attention skills in children, and to study their affects on learning.
5. Studying the development and application of encoding skills in children from different backgrounds could allow the investigation of effects on learning across a range of selected content areas and skills.

3. Science of Learning - Practice and Environments

This chapter describes the practices and environments that shape learning throughout life. The emphases and mixes of formal and informal learning vary at different stages of life. Informal learning occurs throughout life, on a daily basis, sometimes in concert, sometimes in conflict with, and often independently of, formal learning. Prior to commencement at school, most learning is informal. During the schooling years, informal learning is replaced by the more directive formal education. Once in the workplace learning is also enabled through non-formal learning activities, through programs of instruction that do not lead to a formal qualification.

Learning occurs at different levels in both formal and informal environments. In *Chapter 2*, learning was defined as the encoding and later retrieval of knowledge in long-term memory. The knowledge retrieved can be declarative, as in the answer to a question, or procedural, as in the rules that govern driving a car and chess playing. Learning can also be defined in terms of the observed impacts of knowledge as an enduring change to behaviour, or in the capacity to act in a given way, that results from practice or other forms of experience (Shuell, 1986).

To be effective, all learning environments must do more than impart knowledge. They must provide opportunities for practice of a skill to the point that it can be used effectively beyond the specific learning context. This will often mean making mistakes, being willing to persist and learn from these mistakes, and the provision of assessment and feedback to refine responses.

These seemingly simple requirements present challenges to the design and resourcing of many formal learning environments in modern societies, while many naturally occurring, informal learning environments, such as video and computer games, often meet them with surprising efficiency. In the face of this imbalanced competition for the attention of children, the guidance and support of teachers remains critical to capturing the benefits of informal learning in the formal learning environments of schools.

Key point

An important form of learning, deep learning, occurs when individuals grasp underlying big ideas and can see patterns in information and also understand the limits to the application of ideas (Schraw, 2006). Transfer of knowledge from the area now mastered to other areas can be greatly facilitated once this is achieved. This type of learning is crucial to adapt to new situations and challenges.

3.1 Formal environments

3.1.1 Framework

Learning in formal educational settings

Under the dominant paradigm applied to schooling, the role of teachers is to deliver the curriculum, the role of students is to learn, the role of assessment is to establish how much of what teachers have taught students have learned, and the role of reporting is to communicate the results of this process for individual students. There are high quality (A-grade) outcomes and low quality (E-grade) outcomes of the teaching-learning process.

In order to make this paradigm work within existing resource constraints, it is common in school education to group students and to act as though all students in a group have similar learning needs. This is true in relation to age and grade groupings, and other groupings of students.

The assessing and reporting of learning in formal education contexts are driven by a 'production line' paradigm designed for mass schooling and delivering education in large schools and universities with large classrooms. Under this model, there is an assumption that individuals of the same age are more or less equally ready for the same curriculum (Darling-Hammond, 2004).

However, under this paradigm, many achievement gaps remain as large as they have ever been. For example, differences have been observed in the average achievements of boys and girls, Indigenous and non-Indigenous students, and students from lower and higher socioeconomic backgrounds. Educators have often concluded that special education programs for boys, or for Indigenous students, or for students from low socioeconomic backgrounds, are the solution.

The hope has been that ways can be found to ensure that all children in a year level master the curriculum designed for that year level, and move ahead at the same rate. Systems like 'mastery learning' have had this as an objective. But in practice, this has not been achieved on any significant scale, with the variability in student achievement observed in Australia is similar to that observed internationally (Masters, 2009).

Research shows that in any year of primary school, the gap between the top 10% of students and the bottom 10% of students in reading and mathematics is the equivalent of at least five years of school. When the slower average rates of progress in the secondary school years are taken into account, gaps between the highest and lowest achievers become even greater (Masters, 2009).

Results such as these are not surprising in light of the evidence presented in *Chapter 2* which shows that learning is influenced by prior knowledge in long-term memory and motivational states, and that students of the same age are often at different starting points in terms of knowledge and motivation. These differences in starting points that may be amplified by differences in support and access to other forms of guidance, can lead to quite different trajectories through a standardised curriculum. As a result, instead of producing a common level of mastery, the standardised curriculum delivered through the traditional schooling model can produce wider gaps in performance over time.

Case study 1

QuickSmart Numeracy and Literacy Programs

QuickSmart programs have successfully addressed the need to improve the basic academic skills of lower-achieving middle school students in order to narrow the achievement gap. Based on information processing theory (e.g. Bratina and Krudwig, 2003; Ketterlin-Geller et al, 2008), *QuickSmart* aims to improve students' information retrieval times to free up working memory capacity and improve fluency related to tasks such as basic mathematical facts and word recognition. More cognitive resources are then available for the important tasks of problem solving and comprehension. Pairs of students selected from participating schools attend three half-hour lessons a week for 30 weeks during class time. Structured lessons with many opportunities for feedback and success, delivered most often by educational paraprofessionals, are supported by a program of professional development for principals, teacher coordinators, and instructors.

Since 2001, independent (state-wide or standardised tests) assessment results gathered from over 2,000 *QuickSmart* and average achieving students, mostly from New South Wales and the Northern Territory, have consistently demonstrated student growth of two to four years' improvement as measured by effect size statistics. Interviews and surveys of students, parents, teachers, and principals have also yielded consistently positive qualitative data, with many comments indicating generalised improvements for the *QuickSmart* students not only in class, but also in their attitudes to school, their attendance rates and their levels of confidence both inside and outside the classroom (e.g. Graham et al, 2007a; Graham et al, 2007b; Pegg et al, 2007).

A considerable body of research shows that learning is most likely to occur when an individual is presented with challenges just beyond their current level of attainment, in what Vygotsky referred to as the 'zone of proximal development', the region of 'just manageable difficulties' where students can succeed, but often only with the support of others (Vygotsky, 1978).

Ensuring that every individual is presented with such optimally challenging learning opportunities can be difficult in a class of 25 to 30 students of mixed abilities. Many teachers begin classes each school year with only a general understanding of what individuals know and can do, hindering their ability to know what will challenge each individual.

With the wide variation typically found in mixed-ability classes, teachers often teach to the middle of the class. The consequence is that the highest-achieving students are often not challenged, and the lowest-achieving students remain or fall further behind with each year of school.

Tailoring learning

The implications to be drawn from cognitive psychology research regarding the impact of prior knowledge on learning trajectories have long been understood by formal educators, even if acting on that knowledge has often proved to be an intractable problem. In 1968, David Ausubel observed that 'the most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly' (Ausubel, 1968). In order for teaching to be effective, it must be tailored to individuals' current levels of readiness.

Key point

It is manifestly untrue that all children of the same age or year level are equally ready for the same curriculum.

School curricula are often adapted to fit the range of abilities within age cohorts in ways that deny more advanced students the opportunities to deepen their knowledge significantly. School curricula often are described as 'mile wide but an inch deep', that is, they are so broad that it is impossible to cover any topic in any depth. Such curricula work against the development of deep understandings, as do assessments aligned with these curricula, assessments designed primarily to check on how much of this breadth students have mastered rather than their level of conceptual understanding (Pegg, 2003).

Expert-novice studies have underlined the importance not only of developing a wide knowledge base, but also of developing deep understandings of concepts, principles and key ideas that assist learners to structure knowledge and to make sense of new information (Ericsson et al, 1993). Deep knowledge influences what we notice, how we interpret and think about information, and makes it easier for us to remember information and to solve problems. Curricula and teaching practices that are unable to accommodate differences in the starting points of students may limit the opportunities for students at all ability levels to deepen their knowledge.

An important part of any learning process is knowledge about achievements that can be used to calibrate learning, and to change responses when needed. For many learning activities, knowledge about progress and the success of strategies is obvious from the experience of the task. In formal education, naturally occurring feedback is supplemented with grades that are commonly used to describe the outcomes of the teaching-learning process.

Grades serve many functions beyond the guidance they may offer to individual students. One of the important benefits of grades for formal education systems is that they enable comparisons of students for purposes of categorisation and selection. However, social comparison made explicit through grades may have a detrimental effect on learning through the effects on students' motivations and their attitudes to learning.

Under competitive grading regimes, students tend to focus more on performing well on assessments, and are less likely to engage in the risk taking and benefits from the mistakes that can lead to deeper forms of learning. Repeated comparisons of performance can also lead to a fixed mindset (Dweck, 2006) that further undermines motivation for deeper forms of learning, as described in *Chapter 2*. Equally, grades with appropriate forms of framing and guidance can be used to motivate learning.

Alternative assessment regimes need to be considered for their potential to improve learning. For example, a student who receives a D in mathematics this year, a D in mathematics next year, and a D in mathematics the following year, is not only denied the opportunity to see and reflect on their learning progress in mathematics, they are also sent a message that they are a D-student and that there may be something stable about their capacity to learn mathematics.

Most students have little opportunity to see any improvement they make across a year. The learners rarely, if ever, get the chance to improve on the weak points in their prior knowledge on which the 'next topic' content depends.

An alternative, or perhaps complementary, approach to setting expectations for learning would be to set standards for progress. How much progress should be expected of a child in a 12-month period, regardless of their starting point? Such an approach would recognise successful learning, even of individuals who are still some time away from achieving year level expectations.

Key point

Students are more likely to see themselves as successful learners if they are supported to see the progress they are making over time.

3.1.2 The learner

Educational researchers and educators would agree that learning is a personal and ongoing process influenced by emotions and beliefs, where deep learning facilitates knowledge transfer from one context to another. Learning is affected by personality and temperament, and mediated by processes like self-regulation, goal-setting, effort and notions of efficacy (Matthews et al, 2006).

Every individual can be thought of as being on a path of learning and capable of making further progress if motivated and given appropriate learning opportunities. Individuals will construct their own meaning that depends on what they already know and their ability to make personal sense of their world. Those with deep knowledge of a concept have extensive factual and procedural knowledge, but also conceptual frameworks that allow them to organise, remember and transfer knowledge to other contexts.

Self awareness and motivation

Educational research is highlighting the importance of attitudes, beliefs and social support in successful learning. Emotions play a powerful role in brain development and learning. Motivational reactions to learning are developed from an early age, often through family influences (Dweck, 2000; Bandura, 1997). Emotionally supportive learning environments facilitate learning and develop a 'learning culture', where learning is valued and supported, as opposed to a 'performance culture' that defines successful learning in terms of grades and competitive task performance.

Key point

Emotions play an important role in formal educational settings. Students appear to learn and remember best when they are involved in activities that have deep personal meaning. Learning appears to occur most readily when it is motivated by curiosity and a personal desire to understand, and can be inhibited by anxiety and fear.

Successful learning is also facilitated by self awareness or metacognition. Effective learners recognise the limits of their current knowledge and understanding. They are aware of the learning strategies they use and they engage in the conscious deliberative practices of evaluation and analysis during learning. They identify when they need additional information, and are proactive in seeking it out. Effective learners monitor their own progress over time and take responsibility for, and control over, their own learning (Flavell, 1979).

How children see themselves can also affect their motivation to learn. Children begin to construct an image of themselves in infancy (Hoffnung et al, 2009). One of the earliest social categories incorporated into the child's self image is gender. By the time they are three years old, most children know if they are girl or boy, and have well developed ideas about the competencies expected from members of their sex (Trautner et al, 2005). Older students often either adopt or actively reject the idea that they are capable of learning. These ideas can be expected to influence their attitude to learning. While gender stereotyping may wane in the primary school years, it seems to increase again in adolescence. Other stereotypes can similarly be expected to affect specific aspects of a child's motivation to learn.

3.1.3 The professional educator

As a result of his comprehensive meta-analysis of what affects student achievement, Hattie reports that outside the students themselves, excellent teaching is the single most powerful influence on student achievement, as demonstrated in *Figure 3.1*. He has shown that teachers account for 30% of the variance of student achievement. 'It is what teachers know, do and care about which is very powerful in the learning equation.'(Hattie, 2003)

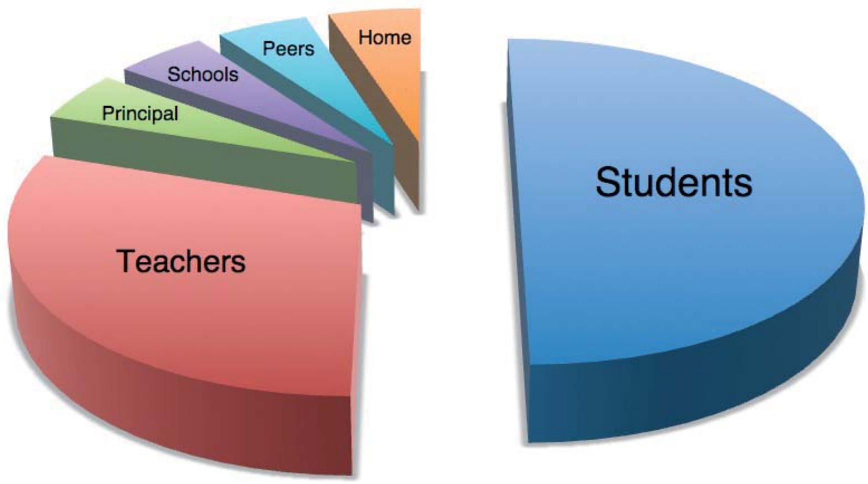

Figure 3.1 Factors that affect student achievement (adapted from Hattie, 2003)

A large body of educational research is focused on teacher practices and the impact of teacher characteristics and behaviours on student learning. This research highlights the need for teachers to have high levels of knowledge in the areas they teach, high levels of pedagogical content knowledge (knowledge about how students learn and how best to teach particular subjects), high levels of commitment and emotional engagement, and the ability to connect with, motivate and engage learners.

Key point

Actions that can be taken by schools and education systems to support more effective teaching include:

- encouraging positive attitudes and beliefs about teachers' own learning, the belief that every teacher is capable of learning how to become a better teacher, an intrinsic motivation to improve outcomes for students, and a recognition that their own learning is a never-ending process;
- providing an environment in which teachers feel safe and supported to experiment and take risks, and have access to necessary resources;
- providing learning opportunities appropriate to individual needs and readiness; and
- creating opportunities for learning in the workplace in the course of day-to-day work.

Good teaching is a key predictor of learning outcomes in school settings (Hattie, 2003). What works for some students tends to work for almost all students. However, as outlined above, teaching and other components of learning environments must be able to take into account the differences in starting points and opportunities of students and must adapt the work accordingly if students are to deepen their knowledge.

Key point

Part of the answer to closing gaps is to ensure that all individuals have access to high quality teaching, regardless of their background.

Recent research has made clearer the importance of 'starting point' assessments. As Fullan et al have observed, 'in an ideal world, the teacher would have precise and current knowledge of each student's starting points and also of what assistance each student requires to move to the next level.' They contrast assessments designed to establish the understandings, misconceptions and levels of attainment of individuals at the beginning of their course, with the more common use of educational assessments to establish how much of what teachers have taught, students have learnt. Having established individuals' current levels of attainment, effective teachers then find ways of matching learning opportunities to these levels (Fullan et al, 2006).

Effective teachers may well be those who are more able to customise learning to individual student needs within the demands of a classroom setting by, for example, paying attention to students' incomplete understandings and naïve conceptions. This requires much more of teachers than the creative delivery of subject matter. To be effective, teachers must be able to actively inquire into students' understandings, and create classroom activities capable of diagnosing and revealing student thinking (Dudley and Baxter, 2009). The customisation or personalisation of learning is discussed further in *Chapter 4*.

The observation that emotions, beliefs and attitudes have a significant impact on student learning suggests that teaching is likely to be most effective when it connects with learners' emotions, encourages positive attitudes and beliefs about learning, and promotes positive social norms and classroom cultures (Dweck, 2000; Pekrun et al, 2002). Effective teachers understand the importance of connecting with individuals' interests and motivations, and of attempting to make learning meaningful and relevant to students' lives.

They understand that learning is more likely to occur when it is motivated by intrinsic factors such as curiosity, than by extrinsic factors such as comparison, competition and the threat of failure, and use this knowledge to create positive learning cultures in their classrooms. They give students the freedom to take risks with their learning and to be relaxed about making mistakes or not knowing answers, and they develop classroom norms that value the search for understanding.

Highly effective teachers also assist students to monitor their own understandings and progress over time, to identify gaps in their understandings, to expect new information to make sense, and to seek clarification when it does not. The more that teachers understand about the basic cognitive and motivational processes that influence learning, described in *Chapter 2*, the better they will be able to help students become better learners.

What teachers must know – the what, why and how

Teachers' quest to know what to teach, why it is to be taught and how to teach it is ongoing, from the day they finish their undergraduate learning to the day they retire from the job of formal teaching. Teachers need to know the content they teach, how to teach, and also the intersection of the two, known as pedagogical content knowledge (PCK) (Shulman, 1986).

With the advent of digital technology there is an additional dimension to this, which Mishra and Koehler (2006) have described as technological pedagogical content knowledge (TPCK). *Figure 3.2* illustrates the kinds of interrelated knowledge teachers need to teach effectively.

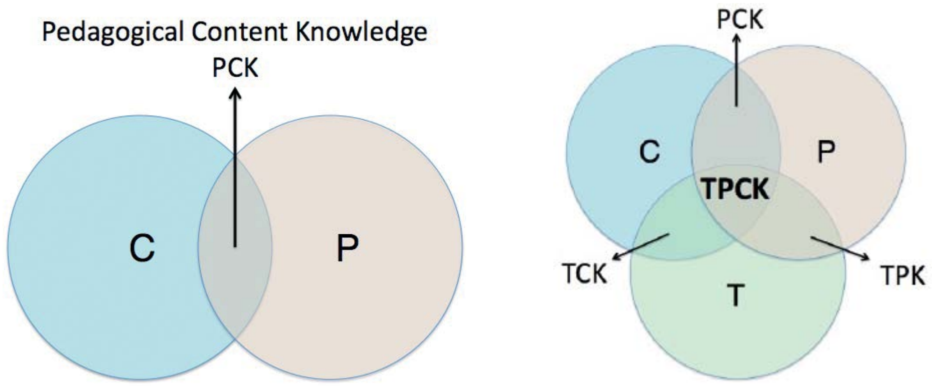

Figure 3.2 Illustration of Content (C), Pedagogy (P) and Technology (T) knowledge that teachers must know in order to effectively teach (adapted from Mishra and Koehler, 2006)

However, while such overarching frameworks that attempt to represent teacher knowledge are very helpful, alone they are insufficient. No number of them can represent the complexity of such knowledge. Mishra and Koehler conclude that '…any representation of teacher knowledge needs to reflect its socially constructed and dynamic nature.' (Mishra and Koehler, 2006)

Similarly, Palmer points to the developmental task confronting teachers who wish to be, and remain, effective throughout a teaching career by noting that when 'face to face with students, only one resource is at my immediate command: my identity and my sense of selfhood', and that '… seldom, if ever, do we ask the 'who' question - Who is the self that teaches? How does the quality of my selfhood form – or deform – the way I relate to my students, my subject, my colleagues, my world?' (Palmer, 1998)

In many industries, lifelong learning is recognised as contributing to successful careers and is supported through a range of developmental programs. In recent years, there have been moves toward teacher accreditation, but as yet there is no national system and teacher accreditation is not linked to teacher remuneration.

3.2 Lifelong Learning

It is widely accepted by trainers and other educators who operate outside formal school settings that adults learn differently from children, and that these differences have significant implications for the design and delivery of learning materials and programs. Since the 1970s, the work of Knowles (1973) has provided the framework for researchers and educators who are interested in the effective training of adults. More recent reviews of adult learning (e.g. Barton and Tusting, 2003) reach conclusions consistent with the principles advanced by Knowles, including:

- adults have their own motivations for learning. They are problem focused and undertake learning for purposes related to their lives outside of education;
- adults have a greater drive to be self-directed, autonomous learners. Teachers play a more facilitative and less directive role in adult learning;
- adults are more consciously aware of their existing knowledge and their learning processes. Differences in adult learning styles can be more easily incorporated into the learning process; and
- most adult learning is through reflection on experiences. A great deal of learning is unplanned, incidental and depends upon the curiosity and reflective skills of the adult.

Many of the assumptions regarding adult learning are consistent with the natural demands of informal learning. The challenge for adult educators is to create programs that allow for self-directed learning within the boundaries of the agreed curriculum, and to present materials in a way that encourages curiosity and active reflection. As previously noted, these lessons from adult learning are not lost on those responsible for formal school education, even if resources and other constraints limit their ability to implement them.

The paradigm of lifelong learning is often deployed to describe our current learning challenges, but it has been rightly pointed out that this often suggests that 'training' is an all-purpose solution for what are in fact emerging structural problems within organisations and society as a whole (e.g. Cruikshank, 2002). In practice, much adult learning occurs at transitional stages in the life-span, when new challenges such as entering the workforce, starting a family or retirement, require learning a new set of skills and, in many cases, some rethinking of the person's self concept.

Life transitions may often lead to 'transformative' learning, which will typically be a mixture of informal and, in some cases, non-formal forms of learning. Other pressures for transformative learning are seen to be emerging due to the unsustainablility of our current patterns of living and working (Lange, 2004). According to these arguments, ecological threats mean that the whole population has to learn to do things differently, and to adopt new paradigms.

Another way of looking at the relative contributions of formal and informal learning as individuals grow and age is captured in *Figure 3.3*.

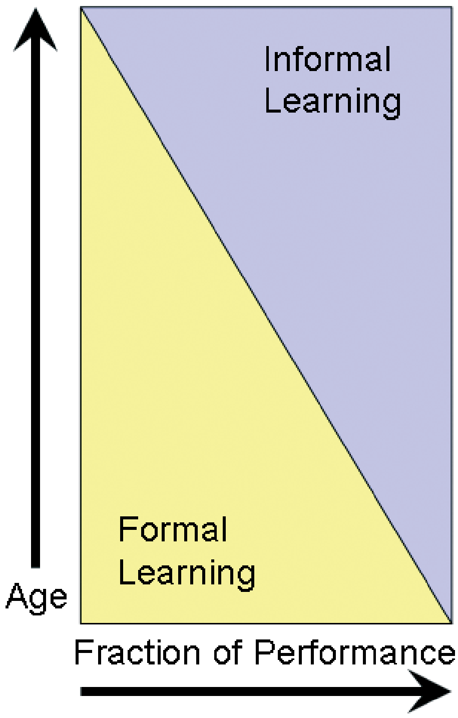

Figure 3.3 The change in the fraction of performance attributable to formal learning and informal earning with age. Adapted from Ackerman (1996)

A recent OECD report notes that learning that occurs outside of the formal system is not well understood, and until the OECD activity on Recognition of Non-formal and Informal Learning, not well researched. The country background report for Australia confirms a focus on the VET sector when recognising non- and informal learning (OECD, 2007a).

3.3 Environmental influences

All forms of learning, spontaneous or directed, formal or informal, grow out of a dynamic interaction between individuals and their environments. Environments provide the opportunities to learn, and support to take advantage of those opportunities. Obstacles to learning can then be created by shortcomings in the individual's capacity or willingness to learn, in the environmental opportunities and support they receive in accessing them, or in a mismatch between the two. Impairments in learning at any stage can form an obstacle to learning at later stages.

3.3.1 Social and health

The strong research foundation necessary for constructively applying the findings of neuroscience to education will come from analysis of the neural, genetic, cognitive and emotional components of learning throughout the lifespan. The relevance of biology to learning is clearly evident when teaching students with disabilities or exceptional talents, so, in part, the promise of neuroscience lies in its careful exploration and description of the entire range of individual difference. Any such exploration of individual differences, however, must also include consideration of how environmental factors work to amplify or modify individuals' strengths and weaknesses with regard to learning (Geake, 2009).

Combining neuroscience with biological and genetic research within frameworks from cognitive psychology can potentially provide links between brain structure and function. This, in turn, may lead to further understanding of the impact of environmental and emotional factors on individuals' development. Recent research into genetic factors that affect learning, particularly reading acquisition (e.g. Byrne et al, 2008), show the importance of biological predeterminants.

The environment, however, plays a crucial role in determining how predispositions translate into developmental and learning outcomes. Specifically, the field of epigenetics explores how environmental factors can either activate or ameliorate genetic predispositions. A 2008 PMSEIC report (Prime Minister's Science, Engineering and Innovation Council, 2008a) notes that,

> 'Epigenetics may also help us understand the observed social inequalities in health outcomes across many diseases. How does social disadvantage influence so many different diseases from infections to diabetes, heart disease and mental illness? It may be that stress pathways, mediated by the hypothalamic-pituitary-adrenal axis and that affect most body organs and systems, begin their influences *in utero* by influencing gene expression. Whilst excessive stress, such as that associated with domestic violence, insecure living conditions and very young teenage pregnancy, is more common in Aboriginal and Torres Strait Islander situations, it is also relevant and very important in any disadvantaged group'.

Social and cultural influences

In considering social and cultural factors that help or hinder learning, it is important to focus on the cultural norms and practices that may be congruent or incongruent with practices evident in the formal schooling context. Rueda and Moll, for example, suggest that it is very important to consider whether students understand how competence is displayed in the classroom, whether students and their families believe that there is an economic, personal or social benefit to school success, how literacy is practiced and valued in the family, and whether cooperation or competition is emphasised in the home and community (Rueda and Moll, 1994).

The social and environmental factors that affect learning include the issue of the digital divide, that is, socioeconomic status and regional disparities in terms of home Internet access (ABS, 2008). Young people with access at home have more opportunity to locate, evaluate and use resources to support homework and to engage in informal learning.

Issues of cultural identity and family history such as long-term and generational unemployment are also vital to consider. Ogbu differentiates between involuntary minority groups (e.g. through colonisation) and voluntary minorities who come into a society through choice (e.g. immigrants). He believes that involuntary minorities experience difficulties in school partly because of the relationship between their cultures and the dominant culture. Involuntary minorities want their cultural identity to be maintained (Ogbu, 1992). Social pressure can, therefore, act to discourage some students from behaving in ways that enhance their school achievement unless they can also preserve their cultural identity. Primary**Connections** and the Stronger Smarter Institute, Queensland University of Technology initiatives address this complex issue (*refer to Case studies 2 and 3*).

The extent of Indigenous student disengagement from education is well documented. This is not a phenomenon unique to Australia and as Castagno and Brayboy note, must be understood within the context of questions about 'power'. Indigenous communities are more likely to disengage from education unless it is considered culturally receptive (Castagno and Brayboy, 2008). That is, an education that '… recognises respects and uses student's cultural identity and background as meaningful sources for creating optimal learning environments.' (Klump and McNeir, 2005)

Gay adds to this the crucial need for 'high expectations' as integral to positive Indigenous student performance (Gay, 2000). The need to cultivate the motivational states conducive to learning described in *Chapter 2*, plus accommodation of the different starting points of students, described above, are also highly important.

Case study 2

Primary**Connections**

Primary**Connections** is an initiative of the Australian Academy of Science in partnership with the Australian Government Department of Education, Employment and Workplace Relations. It is a program that links the teaching of science with the teaching of literacy in primary schools. The initiative aims to increase the quality and quantity of science teaching and learning in primary schools through developing teachers' confidence and competence. This is achieved through a professional learning program supported by quality curriculum resources.

The Primary**Connections** Indigenous Perspective consists of a framework underpinned by six conceptual areas – cultural diversity, relationships and partnerships, quality teaching and learning, students' worldviews, teachers' worldviews and curriculum. The framework supports teachers to incorporate relevant, contextualised and embedded Indigenous perspectives to accelerate science and literacy learning outcomes for Indigenous students. It also aims to increase non-Indigenous students' and teachers' awareness and understanding of Indigenous perspectives.

The project has been monitored by ongoing research and evaluation. Preliminary findings (Hackling and Prain, 2008) are that although all participating students showed improvements in science achievement, Indigenous students, in particular, have benefited from teaching based on Primary**Connections**, with a proportionally far greater improvement compared with their counterparts than was seen in other student groups. Although a gap between the science achievement of Indigenous and non-Indigenous students still exists, the program has demonstrated a mechanism for bridging this gap.

In Australia, significant improvements have also been demonstrated in schools embracing the Stronger Smarter philosophy. The Stronger Smarter philosophy articulates the need to develop and embrace a positive sense of Indigenous student identity, embrace Indigenous leadership in schools and communities, and match high expectations school cultures with high expectations classrooms and high expectations for teacher/student relationships. It also articulates the need for flexible and innovative approaches to school staffing and school modelling (Sarra, 2008).

Case study 3

Stronger and Smarter School Leadership

The Stronger Smarter approach to developing positive school learning cultures has already underpinned some dramatic improvements in student data. Cherbourg State School in Queensland saw a 94% reduction in unexplained absenteeism within 18 month, and an improvement in real school attendance from 63% in 1998 to 94% in 2004. Literacy levels improved by 45% (Sarra, 2003).

Similar positive patterns of improvement have been noted in other schools with Indigenous and marginalised students:

- Rutherford Technical College, New South Wales - Aboriginal school attendance is better than 90%;
- Kubin Island in the Torres Strait, Queensland - attendance has risen from 79% to 91%;
- Menindee, New South Wales - Aboriginal student retention from year 9 to year 12 is 100%;
- Mt Margaret Remote Aboriginal school, Western Australia - attendance is 94%, with students performing above state benchmarks; and
- Glenroi Public School, NSW - Aboriginal student attendance was better than 90%, with dramatic improvements in literacy (Sarra, 2008).

It has been known for many years that the single biggest influence on student school performance, regardless of social and/or cultural context, is the quality of teaching experienced. In the context of Indigenous students, some questions have emerged about the efficacy of schooling in an 'all-Indigenous' environment, compared to a mainstream school environment.

While in some circumstances it is clear that an all Indigenous environment, such as at Cherbourg, has delivered positive outcomes, there have been other circumstances, such as the Victorian College of Koorie Education, in which student outcomes have been dramatically worse in an all-Indigenous environment (Sarra, 2007). Although there is no clear consensus about the efficacy of 'all-Indigenous' or mainstream school settings, there is strong consensus that improved Indigenous or marginalised student outcomes will be improved in school environments in which there is quality leadership, quality teaching, and quality relationships.

Central to this is the need to develop and maintain school cultures of 'high expectations', in which school leadership supports, develops and monitors teaching and learning staff, as well as having the courage to challenge and intervene as required (MACER, 2004). Against this background the important role that school principals and other school leaders play in directing, aligning and resourcing the influence of teachers in schools becomes clear (OECD, 2008).

Research conducted in the USA and Canada (e.g. Walters et al, 2003) and in the UK, Australia and NZ (Robinson, 2007) to assist in pin-pointing specific leadership activities that can advance this chain of positive influence signals that school leaders are now more aware of the importance of building the organisational capacity of their schools to ensure effective alignment of collective expectations, individual responsibilities and school accountabilities (Abelmann et al, 1999), particularly by ensuring greater efficacy in internal accountability measures amongst staff (Newmann et al, 1997).

What we have come to realise is that it takes a whole school community working together to realise a high-expectation culture and to sustain its impacts on student outcomes (Hall and Hord, 2006).

Childhood Environments

The obstacles to learning differ with the stage of development. In the prenatal period, the rapidly developing brain is extremely vulnerable to disruptions likely to impair its ability to mediate learning after birth. Factors affecting the quality of the environment within which brain development occurs, such as illness, malnutrition, stress, use of prescribed or recreational drugs on the part of the mother, or premature birth, have all been shown to be associated with poorer cognitive, social and emotional outcomes in later childhood (Jones and Smith, 1973; Eleftheriades et al, 2006; Bhutta et al, 2002). A broader picture of factors that influence learning across the lifespan is presented in *Appendix E*.

Individual differences in the ease with which children learn exist from a very early age as a result of innate differences in ability and temperament. Differences in the extent to which parents nurture the precursors of the skills called on by schools can actively increase these differences, and may constitute obstacles to later learning. Some parents, for example, have spent more than 1,000 hours reading to their preschool children before they begin primary school, while other parents have not read to their children at all (Adams, 1990). Shared reading exposes children to patterns of grammar and discourse in ways that conversation typically does not. It makes a unique contribution not only to language development but also to early reading achievement (Bus and van Ijzendoorn 1999; Bus et al, 1995).

Even when opportunities to learn are readily available, a child must feel emotionally secure to take advantage of those opportunities. Toddlers who show a secure attachment to their parents explore their environments more actively than children with insecure attachments. Such early exploration provides the basis for successful learning experiences (Ainsworth, 1993). These in turn build up knowledge and produce the sense of competence and desire for mastery that motivates further spontaneous learning behaviour.

Key point

Heckman noted that 'early family environments are major predictors of cognitive and non-cognitive abilities' (Heckman, 2006). When the family environment does not support development, interventions in early childhood are more effective than interventions in adolescence or adulthood.

Not surprisingly, secure attachment is associated with greater competence in both the cognitive and social domains later in childhood (Fisher, 2004). Security of attachment also affects the ease with which parents can engage their infants in parent-initiated activities that build up the culturally valued knowledge that is difficult to acquire through informal learning (Bus and van Ijzendoorn, 1999).

Experiences that impair the development of the security of a child's attachment to their parents can then constitute obstacles at different stages of early learning. Such experiences range from insensitive parenting, that is, parenting behaviour based on the parent's self interest rather than the child's needs (Ainsworth, 1993), to outright neglect or abuse. When neglect or abuse is chronic, leading to persistently high levels of stress in the child, it can affect the developing brain in ways that have long-term effects on cognitive and emotional development (de Bellis, 2005).

Case study 4

Marymead Child and Family Centre Circle of Security Program

Canberra-based Marymead Child and Family Counselling Centre provide counselling services to families with a range of concerns about child behavioural, emotional and mental health issues. The services of the Centre are available to infants and young children under the age of eight years, with up to half of referrals to the Centre being for children from disadvantaged families. The Centre focuses on promotion, prevention and early intervention to address risk factors that result in negative learning, behaviour and health outcomes in later childhood and adulthood.

As part of the services provided by Marymead, from July 2006-June 2007 the Circle of Security program was trialled and evaluated. Circle of Security is a 20-week, group-based (or individual) parent educational and psychotherapeutic intervention that has been shown to support secure attachment in high risk families (Hoffmann et al, 2006). It attempts to rectify child behaviour and emotion regulation problems indirectly by focusing on caregiver-child patterns of interaction. This focus on the relationship between parent and child is the key aspect of the program and is in contrast to other programs aimed at child behavioural problems that direct the intervention at the child utilising the application of consistent, strong, and often negative, responses to eliminate the behaviours.

The program is designed to change patterns of caregiver behaviour using videotaped parent-child interactions for assessment and therapeutic work with the family. The therapists support parents to observe interactions with their own child, to improve their understanding of what the child needs from the caregiver, and their capacity to respond to these needs. The supported use of individualised video clips allows the caregiver the opportunity to reflect on their own and their child's experience in the relationship, leading to improvements in their caregiving.

The outcomes of the initial trial and evaluation were positive, with the approach shown on average to support parent-child relationships and alter negative patterns of behaviour. The Centre has since increased the number of Circle of Security groups conducted each year to four, along with individual therapy. Caregivers have included parents, foster and kinship carers, and adoptive parents. Fathers, as well as mothers, have been involved. Caregivers who have completed the Circle of Security Intervention are overwhelmingly positive about the changes it has made to their relationship with their child, as well as to the child's emotional and behavioural wellbeing.

The transition to high school may mark a particularly vulnerable period in the child's ability to benefit from formal learning experiences provided by educational institutions. A Canadian study (Shapka and Keating, 2005) found that while most aspects of self-concept remain stable or show small increments, self perceptions of academic ability decrease throughout adolescence. The decrease is particularly marked in the first year of high school, suggesting that it reflects the change to a school environment that may emphasise the outcome rather than the process of learning, and competition between students. Shapka and Keating warn of the possibility that schools that follow a more traditional approach to education may obstruct rather than advance learning.

3.3.2 Technology

The availability of technology can serve to personalise learning and consequently enhance learning outcomes when used appropriately.

For many, the emerging digital world has reshaped the way people learn and the transmission of knowledge. For others, it is a tool to supplement the learning process that has, in practice, been long on promises but short on delivery. These differences of opinion reflect the current state of knowledge regarding the storage and transmission of information through digital media, and the impacts of digital media on formal and informal learning, particularly among children.

In summary, current understandings are that:

- the volume of information stored in digital formats is increasing rapidly and will become the dominant non-personal source of information in the next 10 years. This fact has many and wide-ranging implications for learning, including the emergence of electronic search skills as a key competence for both teaching and learning, and the potential for the widening of current educational gaps between advantaged and disadvantaged groups due to differential access to the internet;

- much of the informal learning of children that occurs through play now also occurs through video games. Children between kindergarten and year 12 are estimated to spend more time attentively engaged with video games (up to three hours a day throughout the year) than in curriculum-focused learning activities. Video games have many of the attributes of an effective learning environment, in that they include clear goals, engaging outcomes, repeated practice with feedback, structures that ensure progressive mastery, and they can provide the gamer with a positive social identity;
- the impacts of video games are currently the subject of several research programs and the results seem to point to both positive and negative results, depending upon the structure and content of the games. For example, on the positive side there is evidence of improvements in selective attention (Green and Bavelier, 2003; Green and Bavelier, 2006), and reductions in gender differences in spatial attention and mental rotation cognitive skills (Feng et al, 2007) that are important underpinnings to mathematics and engineering sciences; and
- on the negative side, there is evidence, consistent with early research on the effects of television, that the violent content of games can lead to aggressive social tendencies, particularly in young males (Anderson and Dill, 2000; Manganello and Taylor, 2009).

Technology can support dynamic and multiple representations of information that is not time, person or place constrained. Learners can connect using social networking sites and directly engage in knowledge creation with other learners who may not be physically present at a particular point in time. Most importantly, technology can support learners in a safe environment where they are willing to take risks with their learning. Those who require extra support can do so discreetly, and those that are more capable can be provided with more enriched and complex learning tasks. However, technology should be considered to be a tool and not a panacea that erases all barriers to delivering optimal learning experiences.

The investment and roll-out of technology infrastructure will have a greater impact in supporting student learning if complemented with a reconsideration of learning spaces and teacher development in schools. In particular, how ICT is physically deployed in schools and how students and teachers are supported to manage the technology from a technical, behavioural and pedagogical sense will need to be addressed.

The issue of learning spaces in schools and universities with respect to technology is not new. Much of these discussions began with the original Apple Classrooms of Tomorrow projects of the 1990s (Dwyer et al, 1991; Dwyer, 1994). Long-term planning is required to ensure that the incorporation of technology or the ideas are sustained in individual schools and institutions.

Hew and Brush indicate that barriers to technology integration in K-12 include time (i.e. teachers need time to identify and evaluate technology-based curriculum resources) and technology support (i.e. lack of trained available technical support staff in schools) (Hew and Brush, 2007).

Another persistent theme in practice and research is related to the limited time and funds for teacher professional development. Studies identify teachers' concerns regarding their available knowledge and skills to integrate ICT in terms of pedagogical appropriateness and classroom management issues (Hew and Brush, 2007). When large technology investments by governments (e.g. broadband, computers, learning objects) are not accompanied by the appropriate level of investment in ongoing teacher professional learning, the result is that the technology does not get taken up and used. A recent report from education.au, *Teacher Professional Learning: Planning for Change* (education.au, 2009), suggests that 'only 27% of teachers use ICT effectively in the classroom.'

The Le@rning Federation, a collaboration between all Australian and New Zealand governments, has been developing digital curriculum content and making the resources available to schools through their respective jurisdictions since 2001, representing an investment of some $55M from 2006-07 to 2008-09 (The Le@rning Federation, 2006). State and territory educational authorities are responsible for providing access to digital resources and professional development to help teachers integrate the use of the resources in their teaching.

However, survey-based evaluations reveal considerable variability in teachers' familiarity with and use of resources and with their access to professional development in this area (Freebody et al, 2008a). The trends have become more promising over time but do lend themselves to the conclusion that teacher professional development must be planned and appropriately resourced at the outset of a technology infrastructure investment rather than as an afterthought if teachers are to be in a position to facilitate optimal student learning with technology (Freebody et al, 2008b).

Gaps in research

Whilst advances have been made in understanding the practice and environment of learning, further research is required in order to fill crucial gaps. Example research areas include:

1. The need to study whether the support we have provided to more able and gifted students has resulted in optimising their learning outcomes.
2. There is a need to develop alternative or parallel assessment techniques to enable student learning progress to be measured against what is expected.
3. Learning that occurs outside of the formal system is not well understood and not well researched.
4. There is a need to study the interaction between formal and informal forms of learning and how these two can be better integrated to enhance the effectiveness of formal education, and to develop the skills needed for effective lifelong learning.
5. Exploration of individual differences and how specific environmental and emotional factors work to amplify or modify individuals' strengths and weaknesses with regard to learning is vital.
6. The investment and roll-out of technology infrastructure will have a greater impact in supporting student learning if complemented by a reconsideration of learning spaces in school, how ICT is physically deployed in schools and how students and teachers are supported to manage the technology from technical, behavioural and pedagogical perspectives.

4. Learning in the Future

This chapter addresses how learning might look in the future. It identifies aspects of learning that will stay the same, and what could change to take advantage of new technologies and emerging knowledge from the science of learning, to enhance the learning potential of every individual. This includes the need for investment in an innovative and sustained program of interdisciplinary research and development that integrates knowledge from neuroscience, cognitive psychology, educational research and educational practice.

With coordinated dialogue and collaboration between researchers and educational practitioners, such a program could contribute significantly to the transformation of learning and transmission of knowledge within Australia, while placing us at the forefront of knowledge and practice in the learning sciences.

The research reviewed in *Chapters 2 and 3* stresses that every individual has different learning needs and progresses in different ways and at different rates. This chapter identifies the need for a more personalised approach to teaching and learning. In particular, it describes how student assessment and technology could be used to facilitate personalised learning.

Many of the current aspects of learning will continue to exist in the future and continue to shape learning and the transmission knowledge:

- learning will be lifelong, and will include a mixture of formal and informal learning, with knowledge being transmitted through professional educators, self-directed learning activities, ICT applications, teamwork, interaction with family, peers and colleagues, and through life experiences;
- achievement will follow effort, which will be influenced by the learning skills and attitudes of the learner. Successful learning will be satisfying and motivating;
- students will bring different levels of knowledge, skills and motivations to learning situations and will progress at different rates;
- learning outcomes in formal educational settings will need to be assessed;
- while technology is transforming learning environments, it will not replace human interaction. Teachers in some form will always be integral to learning; and
- there will be a continual need for innovation to improve educational design and learning outcomes in response to new insights from learning science and practice.

Other aspects could change to enhance learning in the future:

- the way learners currently progress through school in age groups. As noted in *Chapter 2*, students are not always at the same starting point at the same age;
- the notion of the classroom as a physical entity and the learning institution as a place. Technology is allowing learners and teachers to be in different locations and to learn anything, anytime, anyhow;
- student assessment could be used as a diagnostic tool to assess individual progress, rather than simply a tool to measure students against a set standard and against each other. Assessment could inform the design and monitoring of personal learning plans to help learners reach their potential; and
- the science of learning will inform the development of technology-based materials and tools to facilitate personalised learning.

4.1 Science of learning in the future

This report has highlighted the contributions that neuroscience, cognitive psychology, educational, health and social research make to our understanding of how we learn, and what promotes or hinders our learning. Until recently much of this research has been conducted in isolation.

Recognition is growing internationally of the need for collaboration among these disciplines, and with practitioners in formal educational settings and other learning contexts. As argued by Bransford (2000), the convergence of the research questions, approaches and techniques from different branches of science provide us with a 'rich picture' of learning and the possibilities for learning.

One initiative in this area is the US National Science Foundation's Science of Learning Center program. *Case study 5* provides examples of the research undertaken at one of these centres, the Temporal Dynamics of Learning Center at the University of California San Diego.

Case study 5

Temporal Dynamics of Learning Center

The Temporal Dynamics of Learning Center (TDLC) at the University of California San Diego is an interdisciplinary research centre that aims 'to achieve an integrated understanding of the role of time and timing in learning, across multiple scales, brain systems, and social systems. The scientific goal of the Center is therefore to understand the temporal dynamics of learning, and to apply this understanding to improve educational practice.' (Temporal Dynamics of Learning Center, 2009)

TDLC-affiliated researchers have developed Fast ForWord, a learning software product aimed at helping children with reading impairments to improve their reading ability. The software was developed from years of research into the science of learning and the discipline of reading. It is claimed to improve reading acumen of all but the most competent readers. Fast ForWord is used in 5000 schools in the USA and internationally and generates profits of US$50M per annum.

Robotics research at the TDLC is providing insights into how the brain works by developing systems that perceive and interact with humans in real time using natural communication channels. Sensors are used to detect and track human faces and to recognise facial expressions that serve as a basis for designing robots that develop and learn to interact with people on their own. Applications include personal robots, perceptive tutoring systems, and systems for clinical assessment, monitoring, and intervention.

The TLDC is funded through the US National Science Foundation's Science of Learning Centers program that aims 'to advance the frontiers of all the sciences of learning through integrated research; to connect the research to specific scientific, technological, educational, and workforce challenges; to enable research communities to capitalise on new opportunities and discoveries; and to respond to new challenges.' (National Science Foundation, 2009)

Key point

The important aspect of an interdisciplinary approach to the science of learning is the need for an interface with educational practitioners who should contribute to the direction of the research agenda of the science of learning and implement the research findings in education settings (Geake, 2009).

Findings from interdisciplinary research will inform the development of innovative approaches to teaching and maximising learning outcomes that will need to be tested in real world environments. The interface between science and practice suggests the need to put structures and resources in place to foster this collaboration. This means researchers from different disciplines working *in situ* with teachers, parents and carers, and learners, and is the basis of the key recommendation of this report.

Recommendation 1

The Expert Working Group recommends the establishment of a Science of Learning Program, delivered through a number of interdisciplinary, inter-professional Science of Learning Centres.

These Centres would involve the integration and cross-fertilisation of numerous disciplines including cognitive science, neuroscience, psychology, social science and education, whilst ensuring the active inclusion of teaching and training practitioners in setting the research direction, as well as disseminating and ensuring optimal application of the findings. The research would address practical problems that hinder learning, from the basic science of optimising learning through to tackling issues relating to Indigenous learners, learners in regional and remote locations, and learners from underprivileged backgrounds.

The following focus areas for Centres are recommended as a potential first step:

- Science of Learning Practice – learning from and sharing best practice in learning, discovering and disseminating its scientific basis.
- Science of Learning Environment – studying environmental impacts on learning, including the forms and processes of learning in formal and informal settings, and integrating this with an understanding of the basic brain, cognitive and motivational processes that influence learning.
- Science of Learning Process – researching the basic science of learning in areas such as neuroscience, cognitive psychology and motivational theory, applying these findings to the development of transformational and highly effective new teaching practice.

The Science of Learning program would:

- be interdisciplinary and involve collaboration between researchers and educational practitioners;
- form collaborations with live educational settings, 'living laboratories' (labs), in order to provide a testbed for the transference of new insights in the process of learning into practice, and encourage the adoption of new teaching methods;
- enable science to inform practice, and practice will inform and drive the scientific research programs;
- involve a diverse array of educators including parents, carers, relevant health practitioners, teachers and trainers;
- ensure wide dissemination of results and very strong links with practitioners;
- lead to theories that can be tested using neuroscience and cognitive psychology so that the underpinning science behind why best practice strategies work can be understood;
- address gaps in research including those identified in this report (see gaps in research at the conclusion of *Chapters 2 and 3*), and investigate and evaluate non-traditional models of schooling to establish an evidence base to guide innovations in education;
- address practical problems that hinder learning, such as issues relating to Indigenous learners, learners in regional and remote locations, and learners from underprivileged backgrounds; and
- work together to learn from each other, and include a formal structure to facilitate this. The Centres might incorporate, or be networked, with existing Centres.

While the outcomes of the research cannot be predicted, it is clear that this interdisciplinary and collaborative approach will have a transformational impact that will revolutionise learning, bringing significant and differential advantage to Australia.

In particular, the involvement of teachers and parents will be valuable research in development and learning at preschool and school age as:

- much developmental research lacks ecological validity because it is based on experimental paradigms far removed from daily life. Involving parents and teachers early in the process of designing experiments could be the basis for developing experimental paradigms with greater ecological validity;
- it will focus researchers on questions that are relevant to parents and teachers, not just researchers. Research in clinical psychology is enriched by the existence of practitioners who are also researchers. Educational research would similarly be enriched by closer involvement of teachers and parents in the selection and study of areas for investigation;
- it will make the transfer of any relevant results to daily life situations easier; and
- it is a way of educating teachers and parents about current theories about development and learning.

A large-scale collaborative science of learning program with government support, in which day-care centres, preschools, schools, tertiary institutions and other organisations engaged in learning are actively encouraged to act as living labs, would give researchers access to representative samples of the population. The goal would be to work with a number of institutions at each level, ideally from quite different areas of a city and from different rural areas, so that a wide range of backgrounds are represented in studies. Institutions could be encouraged to become living labs by giving them input into the selection of research topics, by providing feedback from the Science of Learning Centres to participating institutions and by providing in-service training for the staff.

Case study 6

Australian Science and Mathematics School

The Australian Science and Mathematics School (ASMS), established in 2003 and operating in partnership with Flinders University, is a public school for senior secondary students (Years 10–12) in Adelaide. Its vision is that it 'will be recognised for its leadership of innovation and reform of learning and teaching in science and mathematics' (Australian Science and Mathematics School, 2009).

The partnership with Flinders University facilitates interaction between students, teachers and researchers. Through this partnership the ASMS is developing an innovative curriculum focused on new sciences such as Biotechnology, Nanotechnology, Photonics and Aquaculture, that links science learning with real world issues and problems. The curriculum is designed to facilitate self-directed inquiry-based learning.

In consultation with their tutors, students develop and monitor personalised learning plans (PLPs). Based on the success of the development and trial of PLPs at ASMS, from 2009 they have been implemented for Year 10 students across South Australia as part of the new South Australian Certificate of Education.

The ASMS runs an extensive teacher professional development program that reaches beyond the ASMS, allowing access to the approaches and practices developed and implemented at the ASMS to educators outside of the school. In 2008, 443 Australian and international educators participated in ASMS professional development programs. The ASMS also assists with the pre-service education of teaching students at Flinders University.

Bissaker undertook a six-year investigation of the processes and outcomes of teachers' professional learning at ASMS and found that 'the investment in teachers as learners was pivotal to achieving the vision of transforming science and mathematics education in the senior secondary years at this school' (Bissaker, 2009).

4.2 The Brain in the future – the neuroenhancement debate

Advances in the neuroscientific understanding of the brain will continue to inform the development of drugs to improve cognitive functioning in people suffering from mental and mood disorders such as depression, attention deficit hyperactivity disorder and dementia. Some of these drugs will find an enthusiastic market amongst mentally healthy people aiming to boost their cognitive performance.

On a cautionary note, critics of neuroenhancment are claiming that mentally healthy people are being misdiagnosed and prescribed drugs such as Ritalin® to enhance attention and other cognitive processes (Hall, 2004). The use of pharmaceuticals for non-medical purposes raises ethical and safety issues, and raises questions about the implications of our understanding of 'human nature' and of ourselves as individuals. Hall notes that a debate is needed about neuroenhancement and how the industry will be regulated (Hall, 2004).

4.3 Educators in the future

Parents are usually the primary educators in the first years of a child's life. While the involvement of childcare workers and early childhood educators in infant education is increasing, and will most likely continue to increase, parents will continue to be key educators of infants. Findings from interdisciplinary research about how infants and young children learn will need to be translated into programs and resources to assist parents to take a proactive approach to their children's early learning, to take advantage of the sensitive periods for developing particular kinds of skills, and to prepare them for formal education.

Professional educators are, and will remain, central to the process of the formal transmission of knowledge transfer for older children, adolescents and young adults. Transform teachers' pedagogy and the learning of children will be transformed, as it is the teacher who controls what formal learning is delivered and how. As Palmer tells us, 'teachers possess the power to create conditions that can help students learn a great deal - or keep them from learning at all. Teaching is the intentional act of creating those conditions, and good teaching requires that we understand the inner sources of both the intent and the act.' (Palmer, 1998)

Key point

Given the key role of teachers, action should be taken to raise the status of teaching as a career in order to attract talented, committed young people. Teachers need to be engaged in on-going professional development and, as part of this, should be encouraged to work towards higher degree qualifications.

4.3.1 Teachers learning from research - from best evidence to best practice

Research is continually uncovering new knowledge that adds to, and transforms, what we understand to be best practice in teaching. Currently, structured teacher learning is not ongoing and this remains one of the impediments to best evidence being transformed to best practice. Teachers are often expected to rapidly implement changes in their practice after minimal and haphazard professional input, and have no real time to reflect upon the integration process that faces them, nor the progress they do or do not make.

The views of respected leaders of educational change depict a world-wide trend that initiatives intended to improve or change the learning experiences of children have been partial and transient at best (Haseloff, 2005). This is largely because the implementers of change are not equipped to implement change.

Key point

In the future, more focus will need to be given to systematic professional development programs that will ensure that all teachers can learn from research on best practice. Successful completion should be rewarded with the formal elevation of a teacher's professional status.

A project entitled '*Longitudinal change for teachers and students in relation to professional learning in statistics education*', led by Professor Jane Watson at the University of Tasmania and funded under the ARC *Linkage Projects* scheme, provides one model for aiding teachers to become knowers of the known, while at the same time furthering the research base. The project provides ongoing interaction between professional learning experts, researchers and teachers. It requires teachers to focus on all forms of teacher knowledge, and is an example of longitudinal situated learning (Lave and Wegner, 1991), something that is critical if best evidence is to lead to best practice.

Teachers also learn directly from observing other teachers. Many brilliant teachers exist within our schools and their skills and experience, when shared, represent a rich, valuable and cost-effective learning resource. The Science of Learning Centres would give the opportunity to understand the science behind effective techniques, highlighting key features. This knowledge could then be broadly disseminated.

4.3.2 Pedagogic change – challenges in the future

Pedagogic change is a complex process that rarely happens quickly. It is most commonly seen only on small scales, when a teacher integrates a single or small set of new concepts into their current practice. School-wide or sector-wide initiatives that require significant pedagogic change are particularly challenging. Haseloff (2005) observes that the process is likely to extend over several years as the learners pass through through discrete stages including:

- thorough investigation of the change proposal;
- candid decision making;
- careful introduction of the proposal;
- timely and inclusive implementation;
- well-supported and well-sustained consolidation;
- evaluation of progress; and
- feedback from evaluation into an improved implementation.

The next 20 years are expected to deliver a rapidly changing world with an increase in knowledge complexity. As teachers begin their careers, they will know little of what will be needed in the years ahead.

Key point

To achieve sufficient pedagogic growth over the span of their careers to ensure they deliver best practice teaching and high levels of student learning, all teachers and education workers, such as assistant teachers and teacher aides will need access to regular, ongoing, structured professional learning opportunities throughout the entirety of their careers.

4.4 Students in the future

4.4.1 Learning will be personalised

Effective learning in the future will be personalised, with formal learning formulated to suit the needs of all students. This form of education will not be limited by traditional notions of schooling, such as yearly progression and classrooms of one teacher and 25 students.

Key point

The goal of personalised learning will be to encourage students to see themselves as learners so that they, their families and their communities invest time and effort into lifelong learning.

Personalised learning will connect children, parents and community resources to construct learning opportunities through collaboration and cooperation. These opportunities for personalised learning will be guided by assessment information that is itself personalised and responsive. An example program from the UK addressing this plus other educational initiatives is given in *Case study 7*.

Case study 7

The Children's Plan

In December 2007, the UK Department for Children, Schools and Families launched The Children's Plan: Building brighter futures. This comprehensive approach to addressing social and educational issues related to children and young adults includes a call for greater personalisation of learning in order to achieve 'world class standards and close the gap in educational achievement for disadvantaged children'.

Key actions under the Children's Plan include to:

- establish strong partnerships with parents;
- improve the quality of early years childcare and education and the qualifications and access to continuing professional development of workers;
- make teaching a Masters level profession;
- establish a Transition to Teaching program to attract more people with science, technology and engineering backgrounds into teaching;
- pilot new forms of alternative educational provision;
- establish a Building Schools for the Future program to ensure that new buildings make space for co-located services and all new school buildings are zero carbon;
- improve the quality of teaching for children with special educational needs;
- allocate every child a personal tutor as a main contact for parents once students reach secondary school;
- ensure there is more time for the basics so children achieve a good grounding in reading, writing and mathematics; greater flexibility for other subjects; and time for primary school children to learn a modern foreign language; and
- provide all children with teaching tailored to their needs and based on their 'stage not age' – personalised learning puts children and their learning first.

(Department for Children, Schools and Families, 2007)

4.4.2 Moving beyond the current assessment paradigm

As noted in *Chapter 3,* the current assessment paradigm does not facilitate personalised learning. Relatively minor changes and reforms to assessment and reporting practices have been made for many years, and these have not delivered a paradigm shift in the assessment of learning.

A second observation is that some features of the existing assessment paradigm, because they are fundamental to assessment itself, are also likely to be features under any changed paradigm. For example, assessment should fundamentally allow learning to be monitored and expectations for learning to be set and evaluated.

It also seems unlikely that it will be possible to move beyond the current assessment paradigm until we move beyond current approaches to the curriculum and its delivery. As long as we persist with the production line model of schooling, that is,

- design curricula on the assumption that all learners of the same age are more or less equally ready for the same learning experiences;

- deliver one-size-fits-all curricula to age-based classrooms of students; and
- seek to grade the outcomes of this production process,

then it will be difficult to move beyond the current assessment paradigm.

A paradigm shift in the assessment and reporting of learning might result from a change in the question that assessment is asked to answer, from:

- *How well has this student mastered the (age-based) curriculum they have been taught and what grade should they be assigned?*

to:

- *Where is this student up to in his or her learning (regardless of age or grade) and what learning opportunities are likely to be most effective in promoting further learning?*

This distinction is more than the traditional distinction between 'summative' and 'formative' assessment. Under the prevailing paradigm, 'formative' assessment is the process of monitoring a student's progress in mastering the relevant curriculum. What aspects of this curriculum have they not yet mastered?

Key point

The assessment paradigm promoted here is based on a much more personalised approach to learning. Such a paradigm would require clarity about what it means to learn and to make progress in an area of learning.

This would have to be developed from, and informed by, research into learning – how learning typically progresses, how it can be supported, and what kinds of obstacles and misunderstandings commonly impede learning.

Under this paradigm, learning opportunities would be personalised. Rather than being given learning opportunities based on their age or year level, learners would be provided with opportunities tailored to their needs and readiness and, ideally, interests and motivations. Learning expectations would be personalised. While challenging learning goals would need to be set for every learner, these learning expectations will not be the same for all students.

Assessments of learning would also be personalised. Rather than requiring all students in a class to undertake exactly the same assessment tasks, as currently occurs in almost all tests and examinations, tasks would be appropriate to students' current levels of achievement. This is the concept underlying the notions of 'tailored' or 'adaptive' measurement of learning.

Assessment will still need to take multiple forms, including:

- national and international standards-based assessment completed by students online;
- group-based and individual student work; and
- assessment of discipline-specific and cross-disciplinary skills and knowledge.

The reporting of learning would be personalised. Rather than grading a student's performance on the standardised curriculum for their grade, reports would indicate what learning progress a learner had made, recognising that some students can make excellent learning progress in a year, while still being behind the majority of students of the same age. This raises an interesting question about 'standards'. Instead of specifying learning expectations in terms of year-level standards, could standards be set in terms of the learning progress expected of students?

4.5 Improving equity in learning outcomes

In some remote Australian communities, school students do not have access to full-time, qualified teachers and adequate resources and facilities (Calma, 2009; Hughes, 2008). Such fundamental deficiencies diminish or prevent positive learning outcomes and reduce the likelihood that students will attend school, let alone finish school and progress to further education.

Recommendation 2

The Expert Working Group recommends that Australia ensures that all students in remote locations have access to full-time trained and qualified teachers and quality learning environments.

As noted in *Chapter 3,* initiatives such as Stronger Smarter that aim to promote a positive sense of Indigenous student identity, encourage Indigenous leadership in schools and foster high expectations amongst Indigenous students and teachers, have shown strong potential to improve the learning outcomes of Indigenous students.

4.6 Learning environments in the future

4.6.1 Fostering a culture of learning

To realise the learning potential of all members of society, we need to foster a culture where:

- learning is a key priority;
- the importance of knowledge and learning for the future wellbeing of society is acknowledged;
- people are curious and motivated to learn throughout their lives; and
- learning is seen as enjoyable and satisfying. Knowledge from the science of learning about motivation needs to inform future programs to foster motivation in learners of all ages.

The science of learning tells us that many factors affect an individual's capacity and motivation for learning. These include the social and cultural views of learning in family and community. By creating a national culture supporting the value of learning for all ages, genders and cultures, Australia would increase individual motivation for learning, and enhance each person's capacity for attaining and retaining knowledge.

Recommendation 3

The Expert Working Group recommends the introduction of a campaign that embeds the excitement of learning, and the value and benefits of acquiring and sharing knowledge, as integral parts of a modern Australian identity.

This campaign would address the need for learning, not merely as a tool for career preparation and progression, but also as a means to become more resilient and adaptable to the changes expected in an increasingly complex world. The program would use science of learning research to inject excitement into the perception of learning. It would debunk 'brain myths', such as the belief that more mature individuals no longer generate new nerve cells in the brain and have reduced capacity for learning, or the belief that we only use 10% of our brain capacity. It would instead be based on the latest research from the emerging field of the science of learning.

Recommendation 4

As discussed earlier in *Chapter 3*, studies have shown that outside the students themselves, excellent teaching is the single most powerful influence on student achievement (Hattie, 2003). This importance has not always been clearly articulated to the community, and over recent decades teaching has become a career path that is neither well respected nor well remunerated. In order to maximise their impact, teachers need to have high levels of knowledge in the areas they teach, be at the forefront of research into how to teach, as well as maintain high levels of commitment and emotional engagement.

The Expert Working Group recommends the introduction of a campaign to enhance the status and esteem society holds for its teachers. In addition, it is recommended that remuneration and support for their continuous professional development in both pedagogy and discipline studies would reflect the central importance of teaching in learning and learning in teaching.

This would complement the campaign outlined in *Recommendation 3*. In order to become a society that values learning and knowledge, we need to be a society that values and supports the role of teachers and professional educators in preparing every individual to participate in society.

4.6.2 Electronic learning resources

The PMSEIC report on Science and Technology-Led Innovation in Services for Australian Industries considered how technological developments could lead to innovations in education services (PMSEIC, 2008b). It provided a scenario describing how a university student might use a variety of ICT-based methods to participate in education in the future. Much of this is already happening in our universities, but the role of ICT in learning, and the number and diversity of technological platforms and applications, will continue to increase.

A US National Science Foundation report, *Fostering Learning in the Networked World: The Cyberlearning Opportunity and Challenge*, argues that cyberlearning, 'learning that is mediated by networked computing and communications technologies', has enormous potential and that 'without deliberate efforts to coordinate cyberlearning approaches, we will miss the opportunity to provide effective support for the convergence of learning and technology' (NSF, 2008).

It notes that as cyberlearning tools and approaches must be informed by the science of learning, strengthened interdisciplinary and collaborative research programs in this area are required.

In Australia, cyberlearning research should form part of the Science of Learning program (*refer Recommendation 1*).

What we do know is that learning resources will continue to be in a variety of formats, both electronic and the more traditional. Learning resources should also be designed to facilitate personalised learning. Electronic learning resources should have adaptable instruction that can be accessed by all learners according to their personal needs.

A software application, gStudy, developed by Winne and colleagues provides an example of how technology can be used to personalise learning. A brief description of this is given in *Case study 8*.

Case study 8

Learning from Learning Kits

In the Learning Kit Project, Phil Winne and his colleagues developed a multi-featured software application called gStudy that can 'help pull up research on learning by its bootstraps'. gStudy is a shell, meaning it is initially empty of particular curricular content. The software allows learners to study any topic. Content can be presented using a variety of media - text, diagrams, photographs, charts, tables, audio and video clips - any of the information formats found in libraries and on the Internet.

gStudy includes cognitive tools that learners can use to work on and with multimedia information by indexing, annotating, analysing, classifying, organising, evaluating, cross-referencing, concept mapping, and searching it. Learning Kits are the interface through which learners interact with gStudy's content and tools. gStudy logs which tools learners use to interact with learning kits and how the tools are used, generating traces of study activity (Perry and Winne, 2006).

The design of technology based learning objects will be informed by the science of learning. Learning resources and an individual learner's work could be stored on a server and accessed through a variety of ICT devices, including desktop computers and mobile devices. Such technology would be available to learners in learning centres and schools, and would not necessarily require personal ownership.

As noted in *Chapter 3*, the effectiveness of current applications of digital technology in learning environments needs to be thoroughly assessed to inform how their future use can enhance learning outcomes.

Recommendation 5

The Expert Working Group recommends a rigorous evaluation of the many widespread applications of digital technology currently employed in learning settings.

This would include applications within a number of sectors such as medicine (for educating patient groups), and commercial computing (such as flight simulation), distance education learning management platforms and the use of open source software to create learning commons. It would enable evidence-based decisions on which are best suited to enhancing learning for all.

This report has noted that the rollout of ICT infrastructure must be accompanied by a sufficient level of teacher training in the use of the technology (*Chapter 3*). This needs to be addressed to ensure that in the future all educators can use new ICT effectively.

Recommendation 6

The Expert Working Group recommends that additional teacher professional development programs be implemented in order to develop the understanding and skills required for the more effective pedagogical integration of digital forms of learning into curricula planning and presentation for teachers, other learning practitioners and students.

5. Conclusion

Breakthroughs in the science of learning, from both the research and practice perspectives, have the potential to transform how all Australians acquire and retain knowledge throughout their lives. Exploiting this opportunity now will help create a resilient and adaptive nation, better prepared to meet complex challenges and opportunities in the future, and able to yield a competitive advantage across sectors in the global marketplace, including education.

This report has outlined much of the research underpinning developments in cognitive neuroscience that promise to open doors to a science of learning that can transform Australia's future. Further, it identified gaps in our understanding of the process of learning.

The process of learning is complex and is influenced by a diverse range of factors across several disciplines. Learning occurs in formal and informal environments, both of which must go beyond imparting knowledge and provide opportunities for the practice and demonstration of skills and knowledge.

Progress in learning will depend on the integration of relevant disciplines into a common and coherent 'Science of Learning' program. This would require a commitment to, and investment in, an innovative and sustained program of interdisciplinary research and development, and must also involve teaching and training practitioners in setting the research direction and disseminating the findings.

Authors of this report recommend:

- the establishment of a Science of Learning Program, delivered through a number of interdisciplinary, inter-professional Science of Learning Centres;
- that Australia ensures that all students in remote locations have access to full-time, trained and qualified teachers and quality learning environments;
- the introduction of a campaign that embeds the excitement of learning, and the value and benefits of acquiring and sharing knowledge, as part of a modern Australian identity;
- the introduction of a campaign to enhance the status and esteem society holds for its teachers. In addition, it is recommended that remuneration and support for their continuous professional development in both pedagogy and discipline studies would reflect the central importance of teaching in learning and learning in teaching.
- a rigorous evaluation of the many widespread applications of digital technology currently employed in learning settings; and
- that additional teacher professional development programs be implemented in order to develop the understanding and skills required for the more effective pedagogical integration of digital forms of learning into curricula planning and presentation for teachers, other learning practitioners and students.

These recommendations, if adopted, will:

- Yield a resilient and adaptive nation that values learning as a lifelong endeavour.
- Ensure the successful application of breakthroughs in our understanding of the science of learning to the practice of learning.
- Link researchers and practitioners in the field of learning, ensuring that the research addresses practical needs, and is widely applied.
- Address the environmental impacts affecting learning for all Australians.
- Contribute to ensuring that all students have equal opportunity to reach their intellectual potential.

- Embed the excitement of learning and teaching, and the value of acquiring and sharing knowledge, as part of a modern Australian identity.
- Enable evidence-based decisions as to which technologies are best suited to enhancing learning for all.
- Better prepare teachers, other learning practitioners and students for more effective integration and use of digital technology.

In a world increasingly dependent on societies with the individual and collective capability to exercise high-level decision-making and skills based on a rapidly expanding and changing knowledge base, little could have higher priority than investing in the science and the structures that will allow the best environments and processes for learning to be available to all Australians throughout their lives.

Appendices

Appendix A Transforming Learning and the Transmission of Knowledge

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Appendix B Glossary

Amygdala	A small oval structure deep in the brain that is important for the emotional content of new memories. It also plays a role in the sense of smell, motivation, and emotional behaviour.
Anterior cingulate cortex	The frontal part of the cingulate cortex, which resembles a 'collar' around the corpus callosum, the fibrous bundle that relays neural signals between the right and left cerebral hemispheres of the brain. Thought to be especially involved when effort is needed to carry out a task such as in early learning and problem solving, and in functions such as error detection, anticipation of tasks, motivation, and modulation of emotional responses.
Attention	The cognitive capacity to select and focus on information in the sensory environment that is relevant to a particular goal. Attention is a prerequisite for learning.
Cerebral cortex	A thin sheet of grey matter forming the outer layer of the brain surface. It is crumpled and folded to increase its surface area. This increases the amount of grey matter and quantity of information that can be processed. It is often divided into large regions called the frontal, parietal, occipital and temporal lobes. The cerebral cortex plays a key role in memory, attention, perceptual awareness, thought, problem solving, language, and consciousness.
Cognitive process (cognition)	The process of being aware, knowing, thinking, learning and judging.
Cognitive psychology	The study of the mental processes of thought.
Declarative memory	Our store of factual and autobiographical knowledge.
Dopaminergic systems	A neuronal system that is responsible for the synthesis, storage and release of the neurotransmitter, dopamine.
Education	Any process, either formal or informal, that shapes the potential of a maturing individual by transmission of the values and accumulated knowledge of a society.
Educational neuroscience	A trans-disciplinary research field that aims to integrate evidence from neuroscience and educational research to further understanding of how learning occurs and inform development of improved educational practices.
Electroencephalography (EEG)	A technique for studying the electrical activity within the brain by recording from electrodes attached to the scalp.
Encoding	The process through which information is received through the senses, rehearsed, organised and integrated with existing knowledge for storage in long-term memory.
Epigenetics	Explores how environmental factors can either activate or ameliorate genetic predispositions.
Executive functions	A collection of information processing functions whose role is to control and orchestrate the flow of cognitive information processing to guide thought and behaviour in accordance with internally generated goals or plans.
Formal learning	Learning that takes place through a structured program of instruction that is generally recognised by the attainment of a formal qualification or award.
Hippocampus	An area buried deep in the forebrain that helps regulate emotion and memory. It is critical for the formation of new autobiographical and factual memories. It may function as a memory 'gateway' through which new memories must pass before entering long-term storage in the brain.
Informal learning	Learning that results from daily work-related, social, family, hobby or leisure activities.
Knowledge	Encompasses information, skills and understanding.
Learning	The process of acquiring knowledge, skills and deep understanding.
Long-term potentiation	The fact that if two neurons are active at the same time the connection between them may be strengthened. This change ('potentiation') can last for minutes to hours.

Magnetoencephalography (MEG)	A non-invasive method of measuring magnetic fields created by the electrical activity in the brain.
Maturation	The process of becoming mature including the emergence of personal, intellectual and behavioural characteristics.
Memory	The cognitive capacity to store information for later use.
Metacognition	Thinking about thinking. Refers to a level of thinking that involves active control over the process of thinking used in learning situations.
Myelination	The process of depositing a myelin sheath that insulates the axon of the neuron resulting in faster transmission of electrical impulses.
Neuroenhancement	Increasing cognitive functioning through artificial means e.g. pharmaceuticals or nanotechnology.
Neuro-imaging technologies	Technologies that enable detailed images of the brain to be produced in order to further understanding of the brain's activities and processes. Technologies include electroencephalography (EEG), magnetoencephalography (MEG) and functional magnetic resonance imaging (fMRI).
Neurons	A particular kind of cell that is specialised for the storage and transmission of information. Neurons are found in the brain, brainstem and spinal cord and may transmit information to muscles or receive sensory information.
Neuroscience	The scientific study of the nervous system.
Neurotransmitter	A chemical substance that is released from a nerve cell to transmit an impulse from the nerve cell to another cell.
Nondeclarative memory	The name applied to a collection of different memory systems that store a range of different types of knowledge, including motor, procedural and cognitive skills, habits and conditioned responses.
Non-formal learning	Learning that takes place through a program of instruction but does not usually lead to the attainment of a formal qualification or award (e.g. in-house professional development program conducted in the workplace).
Noradrenergic systems	A neuronal system that is responsible for the synthesis, storage and release of the neurotransmitter, noradrenaline.
Parietal lobe	The part of the brain that lies beneath the parietal bone, the main side bone of the skull. It plays important roles in integrating sensory information from various parts of the body, knowledge of numbers and their relations, and the manipulation of spatial information.
Pedagogic change	Alteration in the principles, practice, or profession of teaching.
Personalised learning	An emerging learning paradigm under which learning opportunities are tailored to the needs, readiness, interests and motivations of learners.
Retrieval	The recalling of information stored in long-term memory for a present purpose such as answering questions, solving problems or otherwise guiding behaviour.
Sensitive periods	Age periods or developmental phases that provide optimal conditions for the development of particular abilities.
Stereology	The use of two-dimensional sections to make interpretations and quantifications regarding the three-dimensional structure of a material or tissue.
Synapses	A specialised junction at which a neuron communicates with a target cell. The neuron releases a neurotransmitter that diffuses across a small gap and activates specific specialised sites called receptors situated on the target cell. The target cell may be another neuron, or a specialised region of a muscle cell.
Synaptic plasticity	The process of changing the strength of connections (i.e. synapses) between neurons in response to environmental stimuli. Underpins the brain's ability to acquire and store information.
Synaptic strengthening	The process of increasing the size of a synaptic field and/or the amount of receptors present, in order to enhance the transmission of signal across a synapse.

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Appendix D Detailed technical information

Chapter 2

Brain Imaging Techniques

The two major branches of brain imaging techniques are: those that provide structural information used to image the position of brain tumours; and those that provide functional information used to locate which areas of the brain are active whilst learning. Functional information is particularly useful when wishing to visualise which areas of the brain are active during mental processes such as perception, attention, learning, reasoning, decision making and action.

Brain imaging techniques that have been used to inform the study of learning include:

- Magnetic Resonance Imaging (MRI): used to image the physical appearance and structure of the brain.
- Functional Magnetic Resonance Imaging (fMRI): used to generate images reflecting which brain structures are activated (and how) during performance of different tasks.
- Electroencephalography (EEG): used as a direct measurement of neural activity at very specific moments in time, that can then be related to specific activity.
- Magnetoencephalography (MEG): used as a direct measurement of neural electrical activity at very specific moments in time (as for EEG). Compared to EEG, this method offers the benefit of having no distortion of the signal by surrounding tissue.
- Other methods that have informed neuroscience include autopsy (e.g. to study synaptic density at different ages) and the study of individuals from certain populations such as children with epilepsy or dyslexia. The study of people with acquired brain injury, neurodegenerative disease (such as Alzheimer's) or a certain genetic profile (e.g. Down Syndrome, Fragile X, Fetal Alcohol Syndrome) has also contributed to knowledge in this area.

Some of the methods deliver good spatial resolution and are used when it is important to pinpoint the exact position of brain activity e.g. MRI and fMRI. Others deliver high temporal resolution and are used when it is important to know the exact time at which brain activity occurred e.g. EEG and MEG.

Attention

In humans, recent brain imaging research has revealed that selective attention is controlled by a distributed network of brain areas, each of which controls one or more aspects of the information prioritisation process. The parietal lobe, located bilaterally toward the back of the brain, receives sensory information from the eyes and ears via the related primary sensory cortex. Neurons of the parietal lobe selectively represent information that is most salient and filter out sensory information that is irrelevant or distracting.

Activity within the parietal lobe is influenced by rule-based signals from the frontal lobes that underpin our ability to think flexibly, to reason, and to plan for the future. Neurons in various regions of the prefrontal cortex allow the individual to learn new rules and to implement them in the service of adaptive behaviour.

Sustained attention or vigilance is critical for effective learning. Brain imaging studies have shown that the circuits that underpin sustained attention include the parietal and frontal lobes, and thus overlap to some extent with areas required for selective attention. But sustained attention also relies on subcortical and brainstem regions to provide bottom-up 'drive' to the cerebral cortex. The sustained attention system is strongly modulated by a variety of neurotransmitter systems, including the dopaminergic and noradrenergic systems. Drugs that act on these neurotransmitter systems can alter vigilance in normal healthy individuals, and in those with attention deficits such as ADHD.

A further component of attention that seems crucial for effective learning is known as 'working memory', the ability possessed by most healthy adults that permits us to listen to, encode and repeat back a telephone number. Without working memory, aspects of the world that are attended cannot be effectively retained, and will not be learned for later recall. Recent studies using fMRI and MEG have revealed that working memory processes are subserved by the same neural circuits as those required for selective attention, including the parietal and frontal cortices.

Attentional processes play a major role in allocating cognitive resources within and between tasks and in other aspects of executive control. Such executive processes are subserved by various regions of the prefrontal cortex. These areas orchestrate activity within other brain regions, including temporal and parietal areas, as well as within various subcortical structures.

Brain imaging studies have revealed that the crucial process of monitoring behavioural outcomes, particularly with respect to detecting errors in behaviour, is subserved by the anterior cingulate cortex, a region buried deep within the cerebral hemispheres. Damage to frontal brain areas can profoundly disrupt executive control, while lesions of the anterior cingulate cortex can lead to problems in self-monitoring of behaviour and learning from errors.

Appendix E Factors that influence learning

Factors that influence learning	Infancy	Early childhood	Childhood	Adolescence	Young Adult	Mature Adult	Ageing Adult
Lifelong issues							
Access to and familiarity with technology		x	x	x	x	x	x
Cultural factors – identity, family history		x	x	x	x	x	x
Environmental health	x	x	x	x	x	x	x
Literacy and numeracy issues			x	x	x	x	x
Mental health				x	x	x	x
Physical health, nutrition and exercise	x	x	x	x	x	x	x
Remote and regional issues – lack of social and physical infrastructure		x	x	x	x	x	x
Social factors - poverty, community values, perceived opportunity	x	x	x	x	x	x	x
Social skills, connections and relationships	x	x	x	x	x	x	x
Stress	x	x	x	x	x	x	x
Youth issues							
Child care and preschool	x	x	x				
Parenting	x	x	x				
Sleep		x	x	x			
Formal education							
Access to tertiary education options					x	x	
Curriculum design		x	x	x	x		
Distance from home or daily travel to gain learning			x	x	x		
Quality of teaching and teachers		x	x	x	x		
Recognition of informally acquired knowledge			x	x	x	x	
Adult issues							
Access to employment and financial resources					x	x	x
Aged care issues						x	x
Maintaining motivation and the habit of learning						x	x
Mental fitness and dementia						x	x
Mentoring by older/experienced workers					x	x	
Mentoring young workers as part of a planned transition to retirement						x	x
Time constraints due to work and family pressures				x	x	x	x

Note: x denotes the factors that are known to impact on learning in a significant manner at a particular stage of life.