
BRAIN LESSONS

A contribution to the international debate on Brain, Learning & Education,
based on the results of an invitational conference organised by the Netherlands
Organisation for Scientific Research (NWO)

J. Jolles, R. de Groot, J. van Benthem, H. Dekkers, C. de Glopper,
H. Uijlings and A. Wolff-Albers

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H. Uijlings and A. Wolff-Albers

Brain Lessons. A contribution to the international debate on Brain, Learning & Education, based on the results of an invitational conference organised by the Netherlands Organisation for Scientific Research (NWO).

This report describes the results of an invitational conference organised by the Netherlands Organisation for Scientific Research (NWO) on 5 February 2004. The first version of the report was published in Dutch in May 2005. The present English version is an extended version, published in November 2006.

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SUMMARY

Brain Lessons

The significant advances in brain science and cognitive science in recent decades have helped us map the workings of the human brain better than ever before. The insights that have emerged vary from a better understanding of human behaviour, to that of the processes which influence the development and ageing of the brain, its disorders and capacities. In many practical respects these insights have still to be brought to full fruition however. One of the most interesting research areas at present involves understanding the brain's ability to learn and the question what practical implications this could have for the education of children and adults.

In the Netherlands, recognition of the potential of these new insights on brain and learning for the improvement of educational policies and practical teaching methods has generated a number of important initiatives. In 2002 the *Netherlands Organisation for Scientific Research (NWO)*, in consultation with the *Dutch Ministry of Education, Culture and Science*, set up the *Brain and Learning Committee*. The committee's remit was to stimulate the exchange of knowledge and ideas between the fields of brain science, cognitive science and educational research as well as practice. This culminated in the organisation of a *Brain and Learning Week* in 2004, which included an international scientific symposium, an invitational conference and a symposium for teachers and the lay public around the theme *Brain, Learning & Education*.

The results of the 2004 invitational conference have been gathered in the present report, *Brain Lessons*. This report also expresses the *Brain and Learning Committee's* vision of the direction in which the *Brain, Learning & Education* theme should be developed in the years to come. Although the insights it contains are based on the situation in the Netherlands, the authors are convinced that the report contains information of interest to all those who are currently considering how to further develop the theme with regard to fundamental and applied research as well as to implementation into educational practice. Therefore, this report has been made available in English, in the hope that scientists and educators in other countries will benefit from it and that it will contribute to the international debate.

Brain, Learning & Education

The 2004 invitational conference on *Brain, Learning & Education* brought together many of the leading brain scientists, cognitive scientists, educators and education experts in the Netherlands. Its aim was to discuss the possibility of a trans-disciplinary approach to brain, learning and education. In this approach, brain science, cognitive science and the education sciences would join forces to contribute

to a *New Learning Science*. This project would promote a collective understanding of the applications of brain and cognitive science to education and, conversely, invite educators and practitioners to pose questions of educational interest to scientists.

Ultimately, twenty propositions were framed to further help scientists, educators and policymakers start to develop the *Brain, Learning & Education* theme. Thus, in spite of the diversity of the disciplines represented by the participants, this conference proved that a dialogue between the various disciplines is both possible and desirable. This was a major success for the *Brain and Learning Committee* and it encouraged it to suggest ways to stimulate further cooperation.

The committee recommended, therefore, that special attention be given to improving communication between the various disciplines and fields, as the terminology used by the various disciplines is in need of clarification. It also recommended that scientists (NWO) and policymakers (the Dutch Ministry of Education, Culture and Science) collaborate on the *Brain, Learning & Education* project, as this will ensure effective communication with professionals in the field and help develop policy on educational issues. Furthermore, it recommended that *Brain, Learning & Education* be given a pivotal role in a revised version of the *Cognition 2006-2010* programme.

A Contribution to the International Debate

The present report focuses on the lessons learnt during the 2004 invitational conference in order to lay a foundation for, and contribute to, the future success of a trans-disciplinary project on *Brain, Learning & Education*. It contains an introduction into the importance, approach and aims of this project, as well as a summary of the discussions inspired by the six workshops held at the conference and a discussion of the results. Thus, this report surveys the terrain that must be covered by a trans-disciplinary project and identifies some of the obstacles it may encounter as well as the targets it must set. Due to the scope of the report, the *Brain and Learning Committee* considers the insights it contains also relevant within a wider, international context. The committee's chair, Prof. Jelle Jolles, believes that the work done by the committee could benefit all those who are currently considering how to further develop the *Brain, Learning & Education* theme in their own country, and that the report will contribute to the international debate on these issues.

Below, the twenty propositions that were formulated by the participants at the conference have been summarised for the reader's convenience. The report contains a full assessment of the possibilities and challenges faced by the *Brain, Learning & Education* theme from the perspective of each of the disciplines involved.

These propositions reflect the contributions made on the following subject matters: 1) the possibility of a dialogue between the disciplines and the relationship between them; 2) the future of the *Brain, Learning & Education* theme from the brain science perspective; 3) the future of the theme from the cognitive science perspective; 4) the future of the theme from the education sciences perspective.

Together these propositions provide the basis for an '*agenda for the future*'. The *Brain and Learning Committee* hopes they will provide a useful framework for the development of the *Brain, Learning & Education* theme in coming years, both in the Dutch and the international context.

Elements of a forthcoming agenda for the Future of Brain, Learning & Education

Proposition 1

Yes, it is possible and desirable to conduct and further develop a dialogue focused on the theme of *Brain, Learning & Education* between the different disciplines.

Proposition 2

The dialogue between the different disciplines should be conducted with respect.

Proposition 3

The various concepts dealing with 'learning', 'education' and 'teaching' are in need of clarification.

Proposition 4

Research conducted in brain science and cognitive science has led to insights about learning that have a substantial potential for future use in educational practice, but at present only a small number of these practical applications have been proved to be effective.

Proposition 5

In order to base education on sound scientific foundations, the project needs to generate clear models and theories which will yield testable hypotheses and ensure an evidence-based approach.

Proposition 6

Brain and cognitive science research focused on 'learning' can benefit from access to the large body of knowledge and insights that has been acquired in the education sciences and in educational practice.

Proposition 7

To ensure that the differences between individuals and between learning processes are adequately taken into account in the education of young people, adults and older people, insight is needed into the neural principles (brain structure, brain function, neuro-chemical processes) on which the processing of information and the mechanisms responsible for the plasticity of the brain are based.

Proposition 8

In the debate about brain, learning and education, attention needs to be given to genetic as well as environmental factors. Relevant environmental factors are both biological and psychosocial in nature.

Proposition 9

Brain and cognitive science can play an important role in research aimed at investigating the conditions that influence learning and understanding the brain and cognitive mechanisms responsible for learning. Research into the distinction between explicit and implicit learning as well as into the 'executive functions', which play a central role in adaptation and learning, is of pivotal importance.

Proposition 10

Our capacity to 'learn' and our ability to 'adapt' depend on the efficiency with which we process information and retrieve knowledge already stored. It is important to analyse how the capacity to adapt and to learn changes in relation to age, in children, young people, adults and old people, and to gain insight into the roles played in this by knowledge, information processing and learning strategies.

Proposition 11

Research needs to be conducted into individual differences in cognitive functioning, and into their properties and causes.

Proposition 12

If we are to deepen and broaden our understanding of learning strategies which can be applied effectively in practical settings, it is essential to find out more about the mechanisms that underlie the human brain's ability to learn.

Proposition 13

Information science can make a relevant contribution to a better understanding of the human brain's ability to learn.

Proposition 14

The outcome of the learning process is determined by a large number of factors, only some of which are related to the functioning of the brain. The quality of the learning environment, the way teachers function and the didactic insights and subject-related concepts used, are all major influencing factors.

Proposition 15

It is very important to recognise and better understand the way emotions affect learning and the processing of information.

Proposition 16

It is very important to analyse the effect of motivational processes on learning and information processing.

Proposition 17

The quality of the teacher is a major determining influence on the efficiency of the learning process. More research is necessary into factors that affect the quality of teaching, such as the teacher's own learning ability and development processes, especially those related to ageing.

Proposition 18

A dialogue between scientists and educators is essential to the further development of learning opportunities for young people, adults and older people.

Proposition 19

Research should be conducted into the long-term dynamics of learning processes, including the processes of development and ageing, as well as into functional disorders that can occur during the learning process.

Proposition 20

The education system should shift its focus from a 'course material centred' towards a 'pupil/student centred' approach.

CONTENTS

10 Introduction

Keeping Up With Developments | Taking the Initiative

12 The Invitational Conference

A New Approach | Structure of the Conference

16 Brain Lessons

On Brain, Learning & Education | Workshop 1: Individual Differences in Cognitive Skills | Workshop 2: Cognitive versus Social Learning in Adolescence | Workshop 3: Abstract Thinking, Arithmetic, Mathematics and The Sciences | Workshop 4: Motivational Processes and Learning Attitudes | Workshop 5: Learning Problems | Workshop 6: Learning and Cognitive Functioning in Adults

30 The Future of the Brain, Learning & Education theme:

A General Review

Finding Common Ground | Improving Mutual Relations | Learning the Difference | Implementing Rigorous Standards | Propositions 1 to 6 for an Agenda for the Future of Brain, Learning & Education

36 The Future of the Brain, Learning & Education theme:

The Brain Science Perspective

Unravelling Plasticity | Developing the Ability to Learn | Propositions 7 to 9 for an Agenda for the Future of Brain, Learning & Education

40 The Future of the Brain, Learning & Education theme:

The Cognitive Science Perspective

Understanding How We Learn | Developing Effective Learning Strategies | Propositions 10 to 13 for an Agenda for the Future of Brain, Learning & Education

44 The Future of the Brain, Learning & Education theme:

The Education Sciences Perspective

Taking a Wider Perspective | Unlocking Emotions and Motivation | Regarding Teachers | Filling in the Gaps | Propositions 14 to 20 for an Agenda for the Future of Brain, Learning & Education

48 Closing Remarks

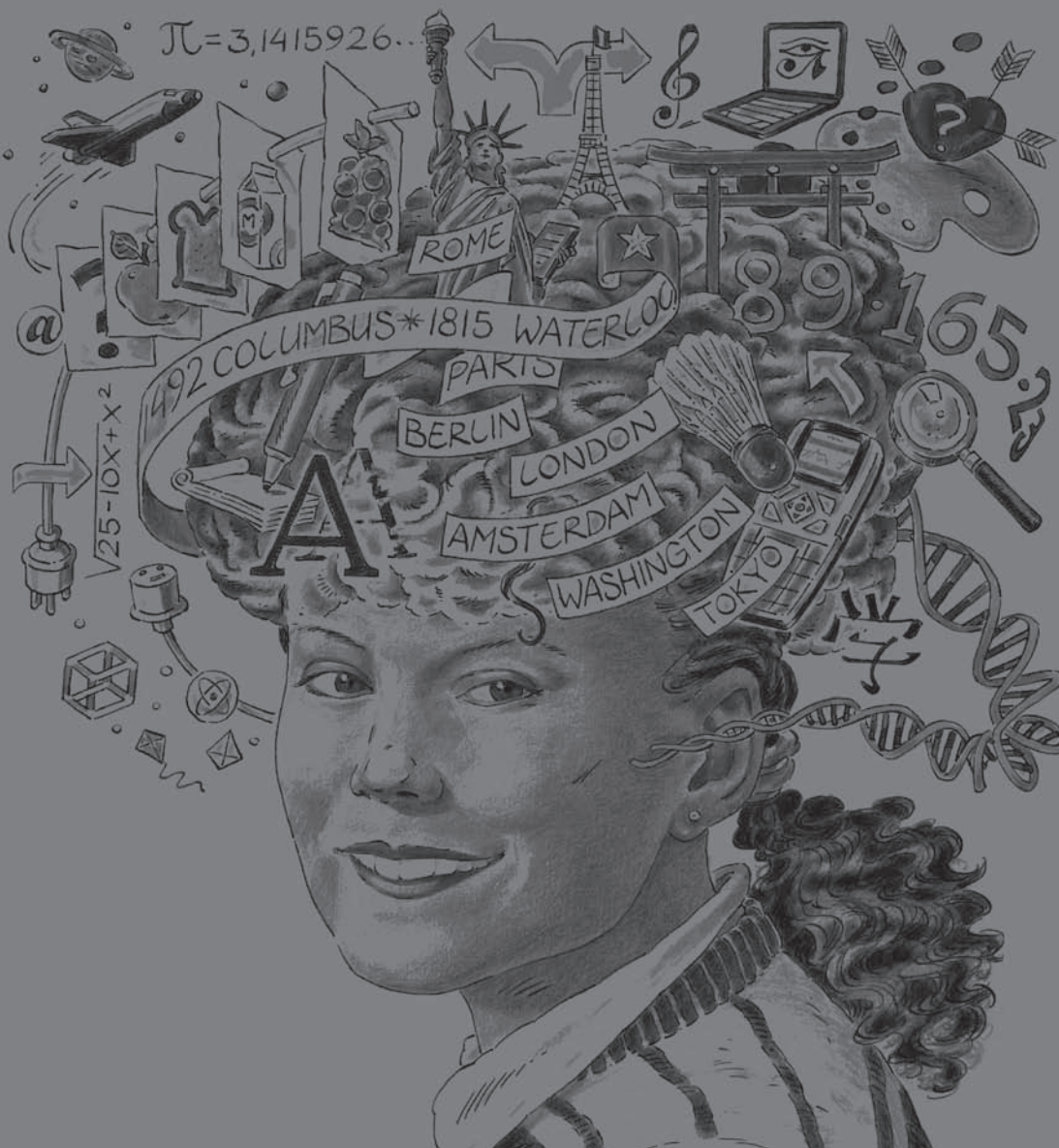
Brain, Learning & Education at a Crossroads | General Recommendations

50 Acknowledgements

51 Recent Publications on the Brain, Learning & Education theme

55 Appendix: Participants in the invitational conference

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INTRODUCTION

Keeping Up With Developments

The pivotal role that education plays in promoting economic prosperity and social progress has made it one of the most important political and social issues of our time. This has stimulated efforts to understand the factors that can lead to educational success, and resulted in new insights which have improved practical teaching methods. Yet much remains to be accomplished and new challenges are constantly presenting themselves. Understanding human beings' ability to learn has become even more important due to growing concerns about learning difficulties encountered by young children, as well as the need to keep an ageing population fit to participate in our fast-paced society.

Significant advances in brain and cognitive science in recent decades, suggest that a new approach to the understanding and improvement of learning might be at hand. Detailed knowledge about the mechanisms that underlie information acquisition, storage and consolidation as well as retrieval, have helped us to map the workings of the human brain better than ever before. Brain networks, neurotransmitters and even genes have been identified that are relevant for learning and memory processes. Consequently, it is of the utmost importance to further investigate how these findings can contribute to the improvement of educational research and practice.

Taking the Initiative

In 1999 the *Centre for Educational Research and Investigation (CERI)*, which is part of the *Organisation for Economic Cooperation and Development (OECD)*, launched a project to examine what implications the discoveries made in brain and cognitive science could have for educational research and policy. This *Learning Sciences and Brain Research Project* was meant to stimulate cooperation between the different disciplines involved and to improve understanding about learning processes across all ages of the human life cycle. This cooperation could clearly contribute to the improvement of education at the pre-school, primary school and secondary school stages. But it was also recognised that it could play a role in improving the cognitive development of adults and older people, and therefore contribute to the project's ambition to promote *Lifelong Learning for All*. This project is now in its second phase (2002-2006) and has led to the setting up of trans-disciplinary networks seeking points of contact between current domains of research in cognitive and brain science on the one hand, and educational practice and policy on the other.

In the Netherlands, recognition of the potential of the new insights on brain and learning for the improvement of educational policies and practical teaching

methods has generated a number of important initiatives. In 2002 the *Netherlands Organisation for Scientific Research (NWO)*, in consultation with the *Dutch Ministry of Education, Culture and Science*, marked the end of the *Decade of the Brain* in the Netherlands by setting up a *Brain and Learning Committee*. The committee's remit was to stimulate the exchange of knowledge and ideas between the fields of brain science, cognitive science and educational research as well as practice. This culminated in the organisation of a *Brain and Learning Week* in 2004, which ambitiously included an international scientific symposium, an invitational conference and a symposium for teachers and the lay public around the theme *Brain, Learning & Education*.

The results of the 2004 invitational conference have been gathered in the present report, *Brain Lessons*. This report also expresses the *Brain and Learning Committee's* vision of the direction in which the *Brain, Learning & Education* theme should be developed in the years to come. Although the insights it contains are based on the situation in the Netherlands, the authors are convinced that the report contains information of interest to all those who are currently considering how to further develop the theme with regard to fundamental and applied research as well as to implementation into educational practice. Therefore, this report has been made available in English, in the hope that scientists and educators in other countries will benefit from it and that it will contribute to the international debate.

THE INVITATIONAL CONFERENCE

A New Approach

The 2004 invitational conference on Brain, Learning & Education was organised by the Dutch *Brain and Learning Committee* with the intention of following-up on the aims stated by OECD/CERI in its 2002 report '*Understanding the Brain: Towards a New Learning Science*'. The foremost objective the committee set itself was to generate debate about the possibility and desirability of a *new approach* to brain, learning and education; an approach which would be distinctive due to its *trans-disciplinary focus*. Thus the question was whether brain science, cognitive science, and the education sciences would be ready to join forces and contribute to a *New Learning Science*, and if so, how this would take shape. As a secondary objective the committee wished to assess which scientific developments and practical advances could contribute to this trans-disciplinary approach to the *Brain, Learning & Education* theme. This required identification of the most promising developments, the goals and the potential obstacles for this new approach. Finally, the committee hoped that it would be able to make an inventory of possible strategies and of the most promising routes for achieving the defined goals.

The results of the conference have been gathered in the following chapters of this report. Besides a substantive introduction to the subject of *Brain, Learning & Education*, it includes a summary of the topics discussed at the conference and an assessment from the perspective of each of the disciplines involved of the possibilities and challenges faced by those who wish to further develop the *Brain, Learning & Education* theme. The conference succeeded in formulating twenty propositions for the further development of this theme.

Structure of the Conference

To accomplish its objectives the committee invited leading brain scientists, cognitive scientists, educators and education experts in the Netherlands to attend the conference. Besides attending plenary sessions, each of the participants was invited to attend two workshops of their choice in which propositions which had been submitted by all those attending were actively discussed.

Six workshops were held in total, and to ensure that they contributed to the aims of the conference the subject matter of each workshop was carefully selected to comply with the following criteria. First of all, the subject matter of each workshop had to provide sufficient points of reference for a trans-disciplinary debate and to ensure that relevant developments in brain science and/or cognitive science could be discussed. Secondly the workshops as a whole had to cover the entire age range adequately, thus ensuring that the pre-school period, childhood and the primary

school, adolescence and secondary education, the education of adults and older people and the learning of skills were all covered. This was in keeping with the OECD/CERI recommendation that our society should set itself the goal to achieve *Lifelong Learning for All* (source: OECD report, 2002). Thirdly, considerable attention needed to be given to the role played by emotions and motivation in addition to cognitive learning. The members of the committee shared the opinion that these factors are an important aspect of the learning process. The fourth element of importance in the selection of subject matters for the workshops, was the need to pay sufficient attention to the case of 'borderline learners', namely people of any age with learning problems.

As a result of these criteria, workshops were held on the following six subject matters:

1. Individual Differences in Cognitive Skills
2. Cognitive versus Social Learning in Adolescence
3. Abstract thinking, Arithmetic, Mathematics and The Sciences
4. Motivational Processes and Learning Attitudes
5. Learning Problems
6. Learning and Cognitive Functioning in Adults

The Participants. Forty-six brain scientists, cognitive scientists, educators and education experts in the Netherlands attended the conference. Nineteen specialists represented the fields of brain science and cognitive science, twenty-one were educators and education experts and six represented other relevant disciplines. (See the Appendix for a list of participants.) Each participant attended the plenary sessions and two workshops of their own choice.

The Preparations. In preparation for the discussions at the invitational conference e-mails were exchanged between the committee members and the invitees. These e-mails suggested a number of potential issues for consideration during the conference and the committee chair formulated forty propositions which were sent to all participants a week before the conference. These propositions suggested points for debate about the following subject matters: 'the question of possibilities and limitations of a dialogue between the different disciplines', 'the brain science perspective', 'the cognitive science perspective', and 'the education sciences perspective'. The propositions were discussed during the six workshops held at the conference.

The Conference. After the opening by Prof. A. ter Meulen, a member of the board of the *Netherlands Organisation for Scientific Research (NWO)*, a plenary session was convened in which the chair of the organising committee set out the theme, goals and approach of the conference. Subsequently, two sessions of three parallel workshops were held, each of which was attended by approximately fifteen invitees. The workshops were chaired by an expert appointed by the committee. The conference ended with a closing meeting which was chaired by a professional facilitator. During this meeting the points provided for discussion by the six workshops were reviewed in order to identify common results as well as the most important targets and obstacles. The results of the conference were summarised in twenty propositions which provide the basis for a forthcoming agenda for the future of the *Brain, Learning & Education* theme.

The Workshops. Care was taken to ensure that all the disciplines were represented at each workshop and each was chaired by an expert appointed by the committee. The chair's role was to initiate the discussion on the basis of a list of prepared propositions and to discuss the subject matter of the workshop. The workshops were to provide points for further consideration in the plenary closing debate. It was expressly stated that reaching a consensus was not the point of these workshops. What was considered important was that each workshop would result in an inventory of opportunities, strategies, pitfalls and other points relevant to the future success of the *Brain, Learning & Education* theme.

BRAIN LESSONS

On Brain, Learning & Education

Our understanding of the relationship between the developing brain, human cognition and the learning process has deepened in recent decades. This has been further enhanced by insights into didactic programmes and classroom techniques. It is still rare, however, to find a scientist or group of scientists with a comprehensive understanding of these matters. Yet, it is clear that a trans-disciplinary approach could achieve a breakthrough in ameliorating our educational programmes.

Such an approach would involve integrating cognitive and neural science research, while developing and evaluating new teaching methods. This would enable us to design evidence-based teaching programmes that respond to the needs of the individual student or pupil, regardless whether this individual is functioning below or above average. At this moment our school system is incapable of engaging the sustained interest of many motivated and intelligent children. It is not properly equipped to fully develop their capacities. Knowledge of the brain and its development during the human life cycle could play a vital role in assisting children to optimally acquire valuable skills.

The invitational conference organised by the *Brain and Learning Committee* in 2004 addressed these issues by organising six workshops which did indeed, for the first time in the Netherlands, bring together a group of brain scientists, cognitive scientists and educators. Before summarising the debates held during the workshops at the invitational conference, a brief introduction will be given into the substantive insights that define the modern approach to *Brain, Learning & Education*.

Processing information. In the modern approach to learning, human beings are seen as complex, *information-processing systems*. This metaphor is used to express the view that as human beings we interact with our social environment and that to function optimally within this complex environment, our brains must optimally select the relevant information available in the environment. To do this we use cognitive processes to filter incoming information and store it appropriately. These cognitive processes depend on attention skills, control processes and learning strategies which help us acquire, store and retrieve information efficiently. Moreover, in recent years it has also become clear that the emotions and motivation form an integral part of the functioning of these cognitive processes.

Learning and memory. The acquisition of new information is generally referred to as *learning*, while the use of previously learned information is referred to as *memory*. Research has provided us with detailed knowledge about the mechanisms that underlie information acquisition, storage and consolidation, as well as retrieval.

Brain networks, neurotransmitters and even genes have been identified that are relevant for learning and memory processes. Cognitive, bio-psychological and neuropsychological research all indicate that there are different kinds of learning and distinct kinds of memory, such as working memory, episodic memory and semantic memory. Thus, the brain processes different kinds of information in different ways and also stores them differently. Hence, motor skills (for example, learning to type) depend on very different brain and cognitive mechanisms than those required for remembering complex visual information (such as the route on a map), and yet others are used for processing verbal-linguistic information (such as learning a language). Studies conducted with patients have revealed that there are also many different kinds of learning and memory disorders, each with their own pattern of brain dysfunctions.

Plasticity. Learning and memory strongly depend on neuronal plasticity. This *plasticity* helps us to learn from early childhood into old age, and enables us to obtain new information in an adequate way from daily interactions with the world around us. Therefore, the brain is a continually developing structure. This development starts before birth and continues into old age. Parts of this development can be suboptimal, for example as a result of disorders (dyslexia, ADHD, autism), social-environmental factors (stress, lack of stimulation, neglect) or incorrect assumptions by the environment (e.g. when teaching schemes are not geared to the development of the student's brain). Importantly, with ageing and as the result of neurodegenerative diseases the processes of learning and memory also change. This is due to cellular and cognitive alterations that lead to changes in motivation, different emotional states and a decline in the capacity of the working memory.

Workshop 1. Individual Differences in Cognitive Skills

Starting Points

Individuals differ significantly in brain development both due to neurobiological characteristics and to various environmental factors. We know for instance that the brains of boys and girls differ due to genetic and hormonal factors that influence the way they develop and mature. Also differences in cognitive learning styles are manifest. Hence, while many girls pre-dominantly adopt a verbal-linguistic approach to learning, many boys make more use of complex visual skills. Other significant factors which result in differences in cognitive skills between people are differences in personality types, in attention span, in emotional responsiveness and in learning speed.

Difference in the quality of individuals' learning environment also has a significant impact and many of the differences in cognitive skills that occur between people are due to this. Family circumstances, various factors related to the nature of schooling and to the experience of stress, are all important environmental factors.

If we wish to improve the quality of learning, we will have to discover how to tailor our teaching methods to deal with these individual differences. To do this effectively we will first have to understand how these differences arise.

Main Results of the Workshop

There are many different types of learning, each of which involves different brain and cognitive mechanisms. Thus, intentional learning differs from incidental learning, declarative learning and the learning of skills, and there is an important distinction between the way episodic memory and semantic memory function.

The various disciplines studying these different types of learning use different operational definitions for them. One of the main tasks for the future development of the *Brain, Learning & Education* theme is, therefore, to make an inventory of the various types of learning and clarify the terms used by the different disciplines. Also important for our understanding of the various learning processes are the differences in quantitative and qualitative learning, the speed of information assimilation, and differences in modality-specific and material-specific forms of learning.

The inventory should also clarify the terminology used to describe the acquisition, retention, consolidation and storage of information involved in the various forms of learning. This inventory will make it possible to identify which specific differences between people are linked to which learning processes, and as a consequence improve our understanding of individual differences.

Both biological variables as well as environmental conditions need to be taken into consideration when examining individual differences in cognitive skills; previous

learning experiences and coping styles could also be important. We know that genetic aptitude is reinforced by the conditions in which someone grows up. Coping styles have a kind of functional plasticity in this respect. This implies that the brain develops in response to new learning experiences. The brain retains its plasticity far into old age, allowing even adults to acquire new skills if the conditions are right.

Individual differences in coping strategies are affected by learning circumstances and learning styles, differences in brain structure, and functional plasticity. The research conducted should therefore be longitudinal and cover all the stages of an individual's learning cycle, from pre-school to adulthood. This would lead to a better understanding of the implications of the neuroscientific, cognitive and behavioural variables and mechanisms involved in learning at various ages. This project is of major interest for the education sciences. Ultimately, the insights we gain from it must be applicable in educational practice.

Points for Further Consideration

Besides *individual* differences between people, we also have to take *intra-individual* variability into consideration. The latter involves differences in cognitive skills that a person might encounter at various stages of his or her life. These differences may even be determined in part by the same factors that influence differences between people. Thus, we not only have to acknowledge that there are differences in maturity and cognitive development between different people, we also have to understand that the brain of the same person does differ in fundamental respects at various stages of that person's life.

More attention needs to be focused on the transfer of knowledge and insights from brain and cognitive science to educational practice. For example, the insight that individual differences exist between children and that they do not develop their cognitive skills according to a fixed pattern, could be used by teachers to offer pupils tasks keyed to the level of their individual cognitive development instead of to their ages.

Many variables underlie the existence of individual differences, such as neurobiological characteristics, personality types, differences in attention span, emotional responsiveness and learning speed. It has yet to become clear whether these characteristics are primary or secondary, and to what extent genetic or environmental factors are responsible for them.

Workshop 2. Cognitive versus Social Learning in Adolescence

Starting Points

The brain continues to develop cognitive abilities and motor skills during adolescence. Adolescence, however, is also the period which is of major importance for the individual's social and emotional development as well as for his or her acquisition of planning and complex problem-solving skills and for learning to anticipate the future consequences of his or her actions. Accordingly, many adolescents are primarily focused on their social environment and on social interaction with their peers. Negative attitudes and perceptions that may arise at this time about the importance of learning ('it's for nerds', 'maths is useless'), can therefore have major implications for the further development of an adolescent's cognitive abilities.

Brain research has recently provided strong arguments for the proposition that the brain - and cognitive function - continues to mature well into the third decade of life. Furthermore, it revealed that the way people of the same age deal with stimuli from their social environment varies greatly. This is largely due to individual differences in brain maturation. Consequently, psychosocial circumstances can have just as much of a modulating effect on the way the brain processes information as biological factors, not only during adolescence, but throughout the whole life cycle.

The education system is one of the most direct ways open to us to create the psychosocial circumstances that will provide adolescents with a positive cognitive and social learning environment. How can recent insights gained from brain science contribute to the success of such an endeavour?

Main Results of the Workshop

As yet we know little about the development of the brain in adolescence. There is strong recent evidence, however, that particular regions in the frontal parts of the brain continue to develop until adulthood. These parts most probably involve structures that form the basis for higher-order cognitive functions and skills. The latter play an essential role in the adaptation to a changing environment and in learning, as well as in introspection, self-evaluation, social monitoring and the control of impulsiveness. More research is required to confirm this, and to translate these findings into concrete approaches which can be used in practical settings. As adolescents are primarily engaged in a process of social learning and the emotional evaluation of their relations with others, including their peers, we also need to investigate the role of culture and psychosocial factors.

There are indications that current teaching material is not well geared to adolescent culture. This situation would be improved if the material was more

in tune with adolescents' primary interests, which would also have a positive effect on their motivation. Problems with motivation are probably more often the consequence of inadequate educational methods than an indication of poor performance. Given the mediocre success current education has with the adolescent age group (young adolescents to young adults), a new approach is necessary. Research methods must combine knowledge of brain and biological mechanisms with insight into the social and cultural factors that play a role at this age. This research should include an analysis of diverse factors such as the role of 24-hour rhythms, the difference between morning and evening persons, the role of emotions and stress ('angry children can't learn'), hormonal changes (which are very substantial during adolescence), the effect of physical activity on learning, and individual learning styles.

Points for Further Consideration

Adolescence is most likely to be marked by a discrepancy between the individual's physiological development (not yet fully mature), psychological development (in many cases already mature in the opinion of the adolescent), and social development (still in progress). These incongruities make special demands on the adolescent's learning environment, which so far have received too little attention.

A better understanding of the brain mechanisms, psychological and social mechanisms that underlie 'curiosity' is needed. Understanding how curiosity functions will help us to find ways to stimulate adolescents' motivation and interests, and consequently indicate ways to improve the learning trajectory. This approach is of utmost importance for the development of 'talent' and the optimal realisation of an individual's potential.

It is not clear whether people are more susceptible to learning certain things during a certain period in their life, even during adolescence. We could for instance even question whether independent learning by adolescents is a realistic goal given the stage of maturity of their brain and cognitive abilities. These questions, and potential differences between the genders in brain maturation, could have far-reaching implications for practical teaching methods.

Workshop 3. Abstract Thinking, Arithmetic, Mathematics and The Sciences

Starting Points

We know that the way our brain deals with language differs significantly from the way in which it processes information relating to arithmetic, mathematics and abstract thinking. Nevertheless, similarities do exist in the higher-order processes that underlie language, arithmetic and abstract thinking.

The question arises, therefore, whether we can encourage interest in the sciences by stimulating the brain processes related to categorising and abstract reasoning? What exactly do we know at present about how these processes work? Can these new insights play a role in tackling development disorders concerning literacy and numeracy skills?

Main Results of the Workshop

The development of abstract thinking in young children is neglected by the current methods used to teach arithmetic, mathematics and the sciences. Research into teaching methods to improve the learning of mathematics and science must therefore also focus on the development of logical analysis and abstract thinking skills in children.

Understanding how the brain functions at the neural level and the behavioural level, as well as the relationship between these levels, will help focus this research. This research should cover a longer period of life than has been the case so far; thus the age range should be extended from 4 to 18, and possibly on into early adulthood. Additional new research needs to be initiated into the pre-school and early school period to study which conditions are necessary during these stages to stimulate the development of future mathematical skills. Of particular importance is a better understanding of the relationship between language and mathematical skills and especially of the overlap between certain higher-order language functions and the reasoning and abstract thinking skills that are so essential to mathematics.

Besides a better understanding of the relationship between language and mathematics, we recommend an in-depth investigation into other skills that play a role in the studying of mathematics in a broader sense. Some such relevant skills are: problem solving, logical analysis, working with multiple representations, spatial awareness, navigation and orientation, classification, comparison, abstraction, reflection and expression. Especially the role and impact of technology needs to be investigated, due to the large amount of time spent on extra-curricular activities related to mathematics, such as playing computer games.

In order to engage student's curiosity and develop the skills required for mathematics and the sciences, the education system should shift its attention from a

focus on course material towards a focus on the relation between the pupil/student and his or her environment. Moreover, this will only be accomplished by training teachers to put these insights into practice on a daily basis.

Points for Further Consideration

Why are there individual differences in language and mathematical skills? Are these differences due to aptitude or does the learning experience also play a part? What exactly does the overlap between language and mathematical skills consist of, and how do the cognitive and brain mechanisms related to either differ? Can we create better 'conditions' for learning mathematics and arithmetic by developing children's spatial skills, orientation skills, the concept of area, abstraction, numeracy and understanding of probability? Should the education system shift its focus from a 'course material centred' towards a 'pupil/student centred' approach?

These questions can only be successfully addressed in a multidisciplinary setting in which brain and cognitive scientists work very closely with educators and professional teachers. We should conduct research that focuses on different age groups and on a range of functions and skills as outlined above. Various methods should be employed, including the observation of behaviour, interviews, cognitive testing and brain imaging studies.

Ultimately, this kind of research will contribute to the development of the *Brain, Learning & Education* theme, as well as yield insights that can be applied directly to the education system in the form of didactic principles, improvements to the pedagogic climate and teaching methods. These insights will be rooted in a theoretical framework that combines findings from the various relevant scientific disciplines and provides testable hypotheses. An approach of this kind will provide a strong foundation for all areas of the education system.

Workshop 4. Motivational Processes and Learning Attitudes

Starting points

Due to brain and cognitive science, we have a better understanding than ever before of the motivational processes at work in the human brain, and the way context and emotions influence motivation. We also know that personal motivation and emotional engagement stimulate the human brain to learn. How can this knowledge be used to improve the learning environment? Can better incentives be developed for encouraging motivation and learning attitudes? Do certain motivational processes actually prove to be an obstacle to learning?

Main Results of the Workshop

There are strong indications that children's natural curiosity is not or not always optimally engaged in the education system. Children's curiosity is probably linked to the human brain's responsiveness to novelty or new stimuli, but we still need more long-term research to understand it properly and find out how it can be used to benefit learning. Learning at school could be organised differently, for example, by providing alternative learning settings, better geared to individual interests. Children's eagerness must be simulated as much as possible, and the learning experiences must be positive, as this helps the brain to process information more effectively.

Research should monitor the educational situation at close quarters and it should address the various aspects of motivation. We need to use our knowledge of the brain and of the cognitive mechanisms that form the basis of motivational processes to understand these various aspects. Special attention should be given to the role played by those regions of the brain that regulate emotion and motivation and we need to gain a better understanding of the implications of damage to the brain and functional disorders.

The development of complex learning skills needs to be studied in greater detail. We need to examine how reflection and intention as well as meta-cognition contribute to better learning skills. We know that the environment in which children are raised is important for a positive appreciation of learning and the development of their sense of reality. By improving the learning context or environment we can therefore enhance pupils' motivation and improve their performance. We should investigate whether there are better ways to link learning opportunities to a child's natural development. Focused neuropsychological research could play a guiding role in this.

Points for Further Consideration

It is essential to investigate in greater depth how children's emotional problems and their attitudes to learning and school affect their performance. A considerable number of children are regularly upset or anxious and have 'arithmetic phobia' or wrestle with other emotional problems. These problems can have a dramatic impact on the motivation to learn.

Cognitive learning strategies should be more closely linked to children's emotional and motivational development and its stages. Providing children with active learning experiences, stimulating them to meet challenges and helping them to attain learning targets are important ways to positively reinforce their motivation.

Workshop 5. Learning Problems

Starting Points

Children with learning problems experience various forms of dysfunctions, such as dyslexia, a difficulty with number skills, or attention deficit hyperactivity disorder ('ADHD'). Adults and older people often have learning problems due to the fact that they have never been able to benefit from an optimal learning environment. There are also cases of both young people and adults who encounter problems with certain cognitive skills due to a slight brain dysfunction.

Brain and cognitive research indicates that an approach focused on the use of 'compensation learning' may offer opportunities for improvement in many cases of learning problems. Clearly, however, making progress is both a question of finding adequate ways to address the different kinds of learning problems and of equipping the learning environment to recognise and deal with these problems at an early stage.

Main Results of the Workshop

The issue of learning problems stands to benefit from an exchange of research findings, views and insights into problems between scientists, educators and teachers. The brain and cognitive sciences can contribute detailed knowledge about cognitive processes and brain mechanisms involved in various functional disorders related to learning problems. This will substantially aid the identification of various disorders and make it possible to intervene more effectively and with a better understanding of the possibilities and limitations of such intervention strategies. We should, therefore, stimulate in-depth investigation, both into the way normal learning proceeds, as well as into various learning disorders.

Educators and teachers are encouraged to call on scientists for assistance more often than they have done in the past, in order to ensure that their methods are backed by scientific findings. One of the recent cases in which scientific research could have made an important contribution had it been consulted, was the decision to introduce the independent 'Study House' system in Dutch secondary schools ('het Studiehuis'). As it turns out, the motivation for implementing this learning method is incompatible with recent neuroscientific findings which show that the brain of children between the ages of 16 to 18 has not yet fully matured. Another case for further scientific scrutiny involves existing political opinions about the speed with which a second language can be learned.

Scientific researchers stand to benefit from closer collaboration with practitioners, as this will result in a more detailed understanding of the problems that occur in practice. Educators, on the other hand, will benefit from the scientific insights with which they can assess and improve policy. A task force of

representatives from a range of scientific and practical disciplines could be set up to further discuss these matters. We must not forget however that a dialogue with practitioners is crucial, for ultimately solutions must be applicable in practice.

Points for Further Consideration

In order to develop effective methods with which to address the learning problems encountered in education, we need to better understand the normal development of learning abilities, as well as to identify the disorders themselves. The focus of this research must be extended to include the pre-school years and the ages of 4 to 18.

We also need to bear in mind that there are significant individual differences between people in cognitive development. The development of functions and dysfunctions can follow different patterns and people make use of different learning strategies, which often depend on their age and background. There are significant differences therefore between the way young and old process information and learn, and between the way people with different ethnical and cultural backgrounds process information and learn. One of the research areas of note with regard to these differences concerns the brain mechanisms and learning strategies involved in learning a second language.

Neuroscience should help us dispose of the 'neuromyths' which unfortunately are still prevalent. One of these myths is the idea that the learning experiences during the first three years of a child's life determine a person's learning potential for life. We have already known for fifteen years, however, that the brain's plasticity makes it capable of learning until far into old age.

Success in addressing the issues related to learning problems at school depends on adequately trained teachers. Future teachers should be trained to understand the brain and cognitive functions involved in the learning process and to recognise learning problems in children. It is important that they be kept up to date on the insights gained from research about learning strategies and that their practical experience is used as feedback in research programmes.

Workshop 6. Learning and Cognitive Functioning in Adults

Starting Points

We know that cognitive functioning slows down quite rapidly as adulthood progresses, and that efficiency in performing complex tasks shows a marked decline as people age. A consequence of the mounting pressure in our society to function at a faster pace is, therefore, that adults are already beginning to encounter difficulties with performing 'daily' tasks under time pressure in their forties. Yet research clearly indicates that, provided enough time to process information efficiently is available, our *ability to learn* barely declines until far into old age.

Insufficient use is being made in practice of data obtained from modern cognitive and neuroscientific research about the learning potential of adults and older people. Especially in the case of adult education, the implications of these scientific findings can yield significant insights. How can these insights be brought to bear on effective learning strategies in this field?

Main Results of the Workshop

As people grow older the biological factors that affect their health or influence the physiological ageing of the brain become more relevant. However, other factors also require investigation if we are to gain a better understanding of the learning abilities of older people. We know, for example, that their learning potential is affected by their own ambivalent attitudes towards learning and training. Thus, motivation and an adequate strategic approach to learning are also important factors.

Individual differences between people make it necessary to distinguish a variety of divergent ageing trajectories. Especially differences in level of education are significant in this respect, and we know that a low level of education forms yet another major risk factor for the ageing brain's learning potential. Educational and counselling programmes which specifically target people with only a basic education can play an important role in addressing these issues. Further research at the level of educational practice is required to determine the risk and safety factors adults face, and especially the adult learning environment is in need of special attention as an influencing factor. Older people must be provided with stepping stones which will help them learn how to be successful at learning. These tools should take into consideration their specific cognitive functions and skills, as well as the age-related changes in these functions and the particular alterations in brain functions already evident in middle age.

Fundamental and applied research also needs to be carried out into the relation between brain plasticity and older people's potential for learning and functional adaptation. Here too, the learning environment plays a significant role and the ways in which adults and older people adapt successfully to a changing environment deserve

further attention. The question which individual personal properties have a modulating effect on functioning should be the subject of extensive study. Personality traits, health issues, various biological variables, variables relating to motivation and to the disposition to actively take the initiative in planning and organizing new activities, all require investigation.

Older employees who have to adapt to the ever-changing demands made upon them by their work environment are an important target group for the learning strategies resulting from this research. It may prove to be important to provide this group with more learning opportunities, which in turn will stimulate their brain to be more receptive to new information. This will help them to adapt more easily. The effects of educational interventions need to be studied closely however, and prominence should be given to evidence-based interventions. The challenges faced by older schoolteachers and lecturers as a group of older employees are of special interest to us. In recent decades this group's work has become increasingly complex, while their declining cognitive skills have not sufficiently been taken into account.

Points for Further Consideration

An agenda for the future of *Brain, Learning & Education* should encourage inter-action on an equal footing between the representatives of fundamental research (brain science, cognitive science), educational research and educational practice. Theories relating to cognitive functioning as people age need to be developed and validated by means of neuroscientific research. At the same time, educational methods need to be based on insights that are supported by evidence.

We have to take into consideration that there are substantial individual differences in people's cognitive ageing trajectories. Identifying and analyzing the various risk and safety factors will enable us to create conditions in which adults, in particular middle-aged and older people, can continue to develop in an optimal way. In this light it is also important to study why some people, as they grow older, become increasingly less open-minded with regard to new experiences, new knowledge and 'staying active in society'.

To be successful, intervention programmes must be specifically tailored to engage the executive brain functions of middle-aged and older people. They must stimulate those functions that activate the pre-frontal parts of the brain. These are the functions concerned with more efficient planning and the use of strategies, with taking the initiative and related functions. This is relevant because there are indications that people who keep mentally active may, to a certain extent, be protected from degeneration. Keeping physically and socially active seems to have the same effect.

THE FUTURE OF THE BRAIN, LEARNING & EDUCATION THEME: A GENERAL REVIEW

Finding Common Ground

Is there a future for a *trans-disciplinary* approach to *Brain, Learning & Education*?

This, ultimately, was the key question the invitational conference, organised by the *Brain and Learning Committee* in 2004, was meant to address. The conference took a hands-on approach to addressing the question and brought brain scientists, cognitive scientists and educators from universities and institutions in the Netherlands together to see whether a meeting of minds or chaos would ensue. Would there simply be endless misunderstandings or would there be enough *common ground* for a respectful dialogue?

All the participants worked very hard to make the conference a success, and also did their best to remove the communication barriers that unavoidably arise from differences in language and disciplines. The only point that might qualify the conclusion that a common ground for debate already exists between brain scientists, cognitive scientists and educators, was marked by the fact that a significant number of scientists did not accept the invitation to the conference, and that educators proved to be more enthusiastic to join the debate.

Especially scientists involved in biomedical neuroscientific research proved less inclined to accept the invitation. The reasons for this vary. However, the organising committee has reason to believe that the main reason for declining an invitation in these cases was due to the fact that although these scientists are involved in ground-breaking fundamental research, they are not focused on the relation between their fields of research and learning. As a consequence, a debate about how their research can contribute to education is a step too far for these scientists. Nevertheless, this is a point that merits further consideration according to the committee, as it is indicative of the kind of obstacles that have to be faced in the search for common ground between scientists and educators.

In spite of these obstacles, the committee firmly believes that representatives of the different disciplines involved do realise that trans-disciplinary cooperation, as suggested by the OECD-CERI in its 2002 report '*Understanding the Brain: Towards a New Learning Science*', is necessary. Moreover, this new approach will not only apply to brain science, cognitive science, the education sciences and educational practitioners; it will also include other branches of science such as cognitive psychology, social psychology, developmental psychology and clinical psychology.

Improving Mutual Relations

It was evident to the committee already before the conference began that substantial misconceptions and misunderstandings between scientists and educators

existed which undermined the future success of the project. These misconceptions were largely due to lack of familiarity with each other's frameworks, concepts and methodologies, or *paradigms*. A main source of contention was identified in the use made of neuroscientific terminology by non-scientists, which has led to instances of inappropriate use of neuroscientific findings in educational practice.

Such misconceptions could have negative implications for communication between disciplines, leading to disagreements based on emotional rather than rational considerations. Therefore, the committee thinks it is of pivotal importance that the frameworks and concepts used by the various disciplines be clarified. The existing distinction between the fundamental and applied sciences should be clear, as well as the fact that various paradigms exist within the major clusters of brain science, cognitive science and the education sciences respectively, as well as in the practical fields associated with each. The committee considers it perfectly appropriate for concepts developed by brain researchers to be used as *metaphors* by educational practitioners, provided it remain clear that these concepts are related to physiological facts.

As all disciplines necessarily imply methodological reductionism, and none can be considered more basic or 'important' than another, the success of a trans-disciplinary approach to *Brain, Learning & Education* depends on improving mutual relations between the disciplines involved. These relations would benefit from a better appreciation of each other's contribution to the project at hand in spite of the differences in approach that evidently and necessarily exist. A sentiment that was expressed by one of the conference participants as follows:

"I wouldn't feel at home at a car mechanics' conference because the operation of an engine, the durability of tyres, the functioning of the transmission, or other desirable or necessary features that are relevant to the optimal performance of a vehicle, are outside the scope of my knowledge and expertise. However, my interest is quickly aroused when I consider related aspects such as the pleasures of travel, choosing destinations for travel, the significance of expanding your horizon and enjoying a car that performs well."

Learning the Difference

The term *learning* is used in many different ways by the various disciplines involved in research and practice and is often the cause of confusion. In the broad area of brain science alone, the term is used to denote various distinct processes related to the functioning of the brain. These differences are conceptual in nature and they become evident once the completely different operational processes investigated

by various researchers are understood. Thus, the learning processes studied at the cell biological and neural level are quite distinct from those studied at the cognitive level, the behavioural level or the educational level.

Substantial dissimilarities also exist between various types of mechanisms underlying processes such as skill learning, cognitive learning and the effects of emotions, motivation and psychosocial factors. The educational context also involves many different types of learning, such as numeracy skills, learning a foreign language or technological skills. Hence it is important to realise that, for example, a completely different kind of learning is involved when an elderly person learns how to use a mobile phone than when an adolescent learns arithmetic.

The committee recommends that confusion related to the terms associated with learning be reduced. Terms such as 'education', 'teaching', 'transfer of knowledge', 'behavioural change', 'transfer of experience', 'transfer of skills' and 'continuous education' require clarification so that it becomes clear which aspect of learning is being referred to. In the light of the significance of *Lifelong Learning for all* as identified by the OECD, the committee also recommends that the term 'education' be preferred to 'teaching', as the latter is associated with formal education (the phase until adulthood).

Implementing Rigorous Standards

The revolutions in brain science and the cognitive sciences over the last three decades, correspond to the development and application of new research methods and a blurring of the boundaries between disciplines. As a consequence, findings and methods from certain sciences became applicable in other disciplines. This has led to a large number of popular scientific articles, brochures and books, published over the last ten years and particularly in North America, in which information about the functioning of the brain is used to recommend new didactic models or techniques. These educational intervention strategies are usually presented as 'practical applications of neuroscientific research'. However, many of them are not based on evidence at all. Moreover, according to a preliminary screening by the OECD, many of the propositions quoted in these publications as 'supported by neuroscience' are simply not correct.

In the light of these developments, the *Brain and Learning Committee* has emphasised that, while it is important to popularise the results of brain and cognitive research, it is also important to ensure that educational interventions meet *rigorous standards of validation and application*. Therefore, the educational interventions referred to, such as Brain Based Learning, should be monitored critically and a responsible and well-founded form of science education about brain and cognition should be set up to ensure that scientific data is not taken out of context.

Substantial progress has been made on the issue of standards in some areas. In the area of applied biomedical research, for example, where strict experimental guidelines ensure the validation and evaluation of interventions in clinical practice. Yet, there are still too few evidence-based methods for the evaluation of interventions in the normal learning process at various stages of life or in skill learning (sport, psychomotor functions, language etc.). A large body of knowledge and experience does exist in the educational field, however, and this can be used both to develop methods to validate the results of research, as well as to discover new areas of investigation.

Rigorous standards of validation and application should therefore become a focal point of the *Brain, Learning & Education* project. These standards should be informed both by insight into the learner's capacities and by an understanding of the learning environment. They can be used to implement a shift in the field of education from practice-based to evidence-based methods.

Propositions 1 to 6 for an Agenda for the Future of Brain, Learning & Education

In this section on the search for common ground between brain science, cognitive science and the educational sciences a number of opportunities and obstacles have been reviewed. The conclusions of this review are summarised below as *Propositions 1 to 6 for an Agenda for the Future of Brain, Learning & Education*.

Proposition 1

Yes, it is possible and desirable to conduct and further develop a dialogue focused on the theme of *Brain, Learning & Education* between the different disciplines.

Proposition 2

The dialogue between the different disciplines should be conducted with respect.

Proposition 3

The various concepts dealing with 'learning', 'education' and 'teaching' are in need of clarification.

Proposition 4

Research conducted in brain science and cognitive science has led to insights about learning that have a substantial potential for future use in educational practice, but at present only a small number of these practical applications have been proved to be effective.

Proposition 5

In order to base education on sound scientific foundations, the project needs to generate clear models and theories which will yield testable hypotheses and ensure an evidence-based approach.

Proposition 6

Brain and cognitive science research focused on 'learning' can benefit from access to the large body of knowledge and insights that has been acquired in the education sciences and in educational practice.



THE FUTURE OF THE BRAIN, LEARNING & EDUCATION

THEME: THE BRAIN SCIENCE PERSPECTIVE

Unravelling Plasticity

One of the most promising prospects for the *Brain, Learning & Education* project, according to the brain scientists who participated in the conference, lies in unravelling the mysteries surrounding the *plasticity* of the human brain. For in the plasticity of the human brain lies the foundation of human beings' ability to learn. It is this plasticity that enables us to continuously store, process and flexibly use information, even when we are advanced in age. Once we understand the principles of neural plasticity, therefore, we will hold the key to optimising the learning environment (for example, a school or a course for older people) in which people learn through explicit instruction.

By studying plasticity we will not only gain insight into neural principles, such as brain anatomy and physiology, cellular and neurochemical processes, but also into the functional adaptation of the brain - functional plasticity. The latter will make it possible for us to understand how best to use the plasticity of the brain to improve human beings' capacity to learn. This will not only benefit normal people (children, adolescents and adults), but also people with diverse functional disorders which can lead to difficulties with memory, attention span, empathy, language, reading or number skills, as well as people with various types of brain damage. Furthermore, it will make it possible for us to establish at a neural level as well as at a behavioural level whether interventions which are aimed at changing behaviour or improving performance prove to be effective.

Developing the Ability to Learn

To make optimal use of someone's ability to learn, it is necessary to create the conditions, specific to an individual, which will optimally engage the brain's plasticity or, in other words, its capacity to adapt. Over the years there has been a long drawn-out discussion about the factors that influence the development of the human brain's various capacities. This led to a dogma conflict about the question whether the higher cognitive functions, including intelligence and our ability to learn, are determined primarily by *genetic* or by *environmental factors*.

This discussion, also known as the 'nature-nurture debate' has proved to be spurious, as in the last ten years research has shown that both factors are important for the development of the mature phenotype. The hereditary factors (genes) can be seen as a blueprint that sets the margins within which the individual develops. The environmental factors, on the other hand, are responsible for the degree to which the genetically determined potential is realised. Examples of important environmental factors are the psychosocial circumstances in which someone grows up, illnesses someone suffers, medicines used, hormonal factors and other biological influences.

The human ability to learn is clearly dependent on the interaction between hereditary and environmental factors. This interaction will manifest itself in the adaptation of the brain during development, and therefore in its plasticity. Yet, very little is known about the relative contribution of genetic and environmental factors and about the biological and psychosocial mechanisms involved. We still do not know, for example, *to what extent* individual disparities in learning abilities depend on genetic or environmental factors.

Many aspects of the ability to learn require further study. These vary from the functions related to attention, the control of impulsiveness, memory and implicit learning, to the more complex aspects such as planning, the role of context and the influence of strategic competences. Especially the executive functions and cognitive control should be the focus of further research, as they are central to cognitive processes in a learning environment. They enable us to learn new behaviour in response to a changing environment, and concern aspects such as efficient planning and the organisation of behaviour, the functioning of our working memory and attention span, impulse regulation, the evaluation of behaviour and self-monitoring. All these sub-functions are important for intentional learning specifically, and for optimal adaptation to a changing environment more generally. Motivation and emotions play a modulating role in this kind of learning process.

We should conduct further research, therefore, into the environmental and genetic factors that affect the brain's ability to perform executive functions and adapt to changing environments. This will lead to a better understanding of such aspects of learning as the forming of concepts, and the development of the higher cognitive functions such as reasoning, intellectual functioning and creativity.

Propositions 7 to 9 for an Agenda for the Future of Brain, Learning & Education

In this section on the future of the *Brain, Learning & Education* theme from the brain science perspective, a number of opportunities and obstacles have been reviewed. The conclusions of this review are summarised below as *Propositions 7 to 9 for an Agenda for the Future of Brain, Learning & Education*.

Proposition 7

To ensure that the differences between individuals and between learning processes are adequately taken into account in the education of young people, adults and older people, insight is needed into the neural principles (brain structure, brain function, neuro-chemical processes) on which the processing of information and the mechanisms responsible for the plasticity of the brain are based.

Proposition 8

In the debate about brain, learning and education, attention needs to be given to genetic as well as environmental factors. Relevant environmental factors are both biological and psychosocial in nature.

Proposition 9

Brain and cognitive science can play an important role in research aimed at investigating the conditions that influence learning and understanding the brain and cognitive mechanisms responsible for learning. Research into the distinction between explicit and implicit learning as well as into the 'executive functions', which play a central role in adaptation and learning, is of pivotal importance.



THE FUTURE OF THE BRAIN, LEARNING & EDUCATION

THEME: THE COGNITIVE SCIENCE PERSPECTIVE

Understanding How We Learn

The cognitive scientists at the conference presented a great deal of new insights into *individual differences in learning ability*. These insights were gained by studying the brain mechanisms involved in the processing of various kinds of information and how these mechanisms differ between individuals and at various stages of life. From the cognitive science perspective, understanding how we learn can help us to develop better methods of instruction. Hence, a better understanding of the various brain mechanisms involved in learning and how these vary with age, will have significant implications for the improvement of education and the attainment of lifelong learning.

One of the ways individuals differ in learning ability is reflected in the kind of learning styles they use. While it is clear that people employ different learning strategies, many questions about how these differences arise still remain unanswered. For instance, some people might learn by using a more 'linguistic' strategy while others might use a 'complex visual/holistic information assimilation strategy', but it is as yet unclear what role individual learning experiences or biological factors, such as gender, play in determining which strategy is favoured. It is also unclear how variable these information processing strategies are. Hence, we need to improve our insight into how these strategies function and investigate whether they are related to individual differences in brain development.

Another significant difference in the way people process information is related to their age. As our experience increases with age, we also become more capable of mobilising knowledge we have already acquired. However, our capacity to process information does slow down as we grow older and we become less efficient at using newly acquired information. Many older people compensate for this slowing down by using strategies that enable them to keep up. For example, an older typist might compensate for her decline in speed by anticipating. This does have a disadvantage, however, as a person's flexibility might decline, with rigid and less efficient strategies as a result. Young people, in contrast, have a surplus of information processing potential and therefore they make more use of their information-driven abilities.

A clearer picture of how knowledge-driven abilities function in contrast to information-driven abilities, can help develop learning strategies that are better tailored to the capacity of various age groups. This could, for instance, mean that older people or people with a brain disorder can be supported by means of cognitive tools that engage their capacity to adapt (functional plasticity) and avoid the entrenchment of knowledge. Young people could be supported by learning which strategies will optimise the acquisition of knowledge in their case.

Developing Effective Learning Strategies

We can only develop effective learning strategies if we know *which* mechanisms form the basis for the human ability to learn (plasticity) and *how* these function. We do know that brain mechanisms associated with the working memory and the executive functions are important for the ways we process information. What implications current knowledge about the brain and its functioning might have for the improvement of cognitive and behavioural interventions is, however, still unmapped. It does seem certain that this knowledge will improve our understanding of learning disorders and of exceptional learning abilities. Thus, further identification and analysis of the way various cognitive processes, and in particular the executive functions, contribute to learning is essential for the development of better teaching methods.

The concept of ‘complexity’ is of particular importance when it comes to analysing how the human brain learns effectively. We already have considerable insight into the formal complexity of structures that people can learn; learning a language is an instance of this. However, there are indications that the efficiency of these complex learning processes has still not been understood. As far as learning a language is concerned, this is due to the fact that no satisfactory models exist for the efficient learning of relevant subclasses of context-free languages. Without these models, the efficiency of human learning processes can only be explained with the help of external factors that can be validated empirically. Examples of these external factors include physical and biological constraints, specific structures entrenched in the brain, bias in the selection of examples used in teaching, and an analysis of the search strategies used by teachers when selecting examples. An empirical investigation of these factors within the theoretical framework of information science could make a relevant contribution to the development of better education in general, and to education geared to learning specific competences in particular.

Propositions 10 to 13 for an Agenda for the Future of Brain, Learning & Education

In this section on the future of the *Brain, Learning & Education* theme from the cognitive science perspective, a number of opportunities and obstacles have been reviewed. The conclusions of this review are summarised below as *Propositions 10 to 13 for an Agenda for the Future of Brain, Learning & Education*.

Proposition 10

Our capacity to ‘learn’ and our ability to ‘adapt’ depend on the efficiency with

which we process information and retrieve knowledge already stored. It is important to analyse how the capacity to adapt and to learn changes in relation to age, in children, young people, adults and old people, and to gain insight into the roles played in this by knowledge, information processing and learning strategies.

Proposition 11

Research needs to be conducted into individual differences in cognitive functioning, and into their properties and causes.

Proposition 12

If we are to deepen and broaden our understanding of learning strategies which can be applied effectively in practical settings, it is essential to find out more about the mechanisms that underlie the human brain's ability to learn.

Proposition 13

Information science can make a relevant contribution to a better understanding of the human brain's ability to learn.



THE FUTURE OF THE BRAIN, LEARNING & EDUCATION

THEME: THE EDUCATION SCIENCES PERSPECTIVE

Taking a Wider Perspective

The representatives of the education sciences at the conference emphasised that the learning process is affected by many factors, only a few of which are related to the functioning of the brain. From the perspective of the education sciences, therefore, the *Brain, Learning & Education* project has to be placed in a *wider context*.

Instruction is based on many kinds of learning interventions. Various tools, didactic insights and subject-related concepts are used. Good, less good and, unfortunately, also poor teachers are involved. Many different factors contribute to the learner's ability to learn and affect learning results.

The education sciences do however acknowledge that the brain plays a significant part in learning; but it is neither the only significant nor the main factor. It is therefore important that the relation between these diverse factors (biological, psychological, psychosocial, environmental, didactic and others) be researched to better understand their role in modulating the learning process.

Unlocking Emotions and Motivation

Emotional development and cognitive development have proved to be factors of equal importance to a child's ability to learn. The OECD 2002 report on the conditions for a *New Learning Science*, focuses attention on the role that self-control and compassion play in emotional development and how important these are to successful learning. The impact of *emotions* can also be negative however, and stress or fear have been found to be detrimental to the efficacy of the learning process. Especially people who, due to a brain disorder, encounter difficulties with learning a skill are susceptible to these negative influences. We need more insight therefore into the way positive and negative emotions affect the learning process, and awareness of them needs to be increased so that teaching methods and learning environments are improved. This would have significant consequences not only for mainstream and special schools for children, but also for learning programmes focused on functionally impaired adults and older people.

Motivation is another major factor of influence on the efficacy of the learning process. We do not yet fully understand the nature of motivation as part of the overall learning process, or the mechanisms responsible for it. Traditionally, the teacher has been an important motivator. However, developments in education over the last few decades have resulted in a marked decline in the role played by teachers due to a focus on 'independent learning'. The implementation of the 'Study House' system in Dutch secondary schools ('het studiehuis') is a modern example of this development. As a consequence much of the responsibility for staying motivated

has shifted to the pupil. Although this approach does have advantages, it is unclear whether the developing brain is already capable of independently taking the initiative to learn and also to do it efficiently and in a 'motivated' way. This question is all the more relevant in the light of recent scientific research showing that functionally the brain continues to mature until into the third decade and that adolescents are nowhere close to being 'finished'.

Regarding Teachers

A major disadvantage of the shift towards 'independent learning' is the loss of a powerful source of motivation in the form of a *skilled teacher* who inspires and expresses why it is fun and important to work on the questions relating to his or her subject. If asked why they selected their subject-matter, almost every scientist or educator replies that a particularly inspiring teacher opened their eyes to it. Clearly, the young brain responds well to a spark of inspiration and we would do well to monitor how it fares without the teacher's presence.

The teacher is undoubtedly of great importance for successful learning. He or she is the one who conveys the knowledge, skills and attitudes pupils need in a changing society and keeps pupils motivated. We need to gain better insight, therefore, into the way a teacher's capacity to process information and acquire knowledge changes with age. Some older teachers are finding it hard to adapt as their role changes to keep up with developments in a society that is becoming more complicated. The effects of 'ageing' on teaching professionals deserves more attention and ways must be found to keep older teachers motivated, as it has become clear from recent studies that older teachers run a higher risk of burnout and that there has been a sharp reduction in the number of older teachers who are still actively teaching a class.

Teachers, educators and practitioners in the behavioural disciplines are also an *important source* of practical experience, information and data for researchers. They are constantly involved in all aspects of learning at a practical level and have expert knowledge about methods for effecting change in behaviour and perception. These practical methods are usually developed on the basis of 'good practice' which is the sum of the practitioner's pre-scientific intuitions, experience and reflection. Scientific findings have not yet been applied to many of these practical situations, and conversely this practical experience has not been used sufficiently by scientists as a source of information or as a means for setting priorities for scientific research.

Filling in the Gaps

One of the problems faced by the *Brain, Learning & Education* project is the fact that essential information is lacking about the way learning and development processes in individuals develop in the long term. The little research that has been conducted does not contain sufficiently frequent measurements. Thus, a good understanding of the long-term dynamics of the learning and development process is not possible at present.

This problem is compounded by our lack of adequate information about the effect of biological, psychosocial and demographic factors on the individual's learning and development process. Interesting phenomena such as intra-individual variability and possible discontinuities in development have seldom been studied. These *gaps in our knowledge* are primarily the result of inadequate (historical) methodological and philosophical choices with regard to the measurement of psychological variables and phenomena. Research into how the brain works does significantly deepen our understanding of learning and development processes, but this in itself does not provide a solution for the fundamental gaps in our knowledge of the long-term dynamics of learning processes. It is important, therefore, that we start to construct a conceptual framework for the understanding of the way learning processes vary throughout the life cycle, which we can use to develop new learning interventions.

We also have too little experience with evidence-based intervention methods at present to be able to assess interventions aimed at improving the learning process, so the committee recommends that the development of evidence-based methods become a priority. In the development of these interventions we must be sure to place the learner and the learning environment at the centre of attention. The interventions should be tailored to meet the needs of various groups, from people with a relatively focal functional disorder (for example dyslexia or dyscalculia) to people with more serious problems, such as functional disorders related to brain injury.

The learner and the learning environment should be the main focus of attention throughout education. This will mark an important shift from a 'course material centred' to a 'pupil/student centred' approach to learning. The latter is concerned with the system of learning as a whole and gives due consideration to subject matter, the pupil, the teacher, the learning environment, learning attitudes, motivational factors, and to both the limiting and stimulating factors involved in learning. All have their place as factors of influence on the learning process.

To effectuate this change, we will need to know more about all aspects of the learner's disposition towards learning in successive stages of life. Insight and knowledge that the *Brain and Learning Committee* feels will best be attained by following the *OECD's* and the *National Research Council's* suggestion to embark on a *New Learning Science* that is based on a trans-disciplinary and multi-modal approach.

Propositions 14 to 20 for an Agenda for the Future of Brain, Learning & Education

In this section on the future of the *Brain, Learning & Education* theme from the education sciences perspective, a number of opportunities and obstacles have been reviewed. The conclusions of this review are summarised below as *Propositions 14 to 20 for an Agenda for the Future of Brain, Learning & Education*.

Proposition 14

The outcome of the learning process is determined by a large number of factors, only some of which are related to the functioning of the brain. The quality of the learning environment, the way teachers function and the didactic insights and subject-related concepts used, are all major influencing factors.

Proposition 15

It is very important to recognise and better understand the way emotions affect learning and the processing of information.

Proposition 16

It is very important to analyse the effect of motivational processes on learning and information processing.

Proposition 17

The quality of the teacher is a major determining influence on the efficiency of the learning process. More research is necessary into factors that affect the quality of teaching, such as the teacher's own learning ability and development processes, especially those related to ageing.

Proposition 18

A dialogue between scientists and educators is essential to the further development of learning opportunities for young people, adults and older people.

Proposition 19

Research should be conducted into the long-term dynamics of learning processes, including the processes of development and ageing, as well as into functional disorders that can occur during the learning process.

Proposition 20

The education system should shift its focus from a 'course material centred' towards a 'pupil/student centred' approach.

CLOSING REMARKS

Brain, Learning & Education at a Crossroads

Preparations for the *Brain and Learning Week* were made between January 2003 and January 2004. It was an ambitious undertaking, involving a scientific symposium with two hundred visitors and ten speakers, an invitational conference with forty-six participants and a day for the public with four hundred visitors. The whole project was made possible by the fact that fundamental substantive starting points on the *Brain, Learning & Education* theme had already been formulated in the OECD report '*Understanding the Brain. Towards a New Learning Science*'.

The *Brain and Learning Week* was an unmitigated success. Its aim was to establish whether the time was ripe to initiate a dialogue across the boundaries of many disciplines and fields. The workshops held during the invitational conference established that there is indeed a willingness to listen to the opinions of people with a different background. Communication is certainly not yet optimal, as emerged during the preparation of the reports on the workshops; it was not easy to distil propositions from what was said that have sufficient 'general' validity. Therefore, this report contains the *Brain and Learning Committee's* selection of points raised during the workshops and highlights viewpoints which could meet with more general approval by various disciplines. The committee takes full responsibility for the selection that has been made.

An unqualified positive result of the workshops was that the general propositions that were submitted to all participants beforehand did lead to debates that deepened understanding and awareness of the issues at hand. As a result, it has become clear to all representatives of the various disciplines that the *Brain, Learning & Education* project is *at a crossroads*: its future depends on taking concrete steps to improve cooperation and sustain the momentum created by the invitational conference. Hence, the twenty propositions for further consideration and assessment provide the basis for an *Agenda for the Future of Brain, Learning & Education* (see sections 4 to 7). These propositions are evidence of the substantial interest expressed by all involved for the elaboration of the *Brain, Learning and Education* theme and its further development.

General Recommendations

While some communication problems between representatives of what is generally referred to as 'hard' science and representatives of the more practical education sciences still remain, these problems are not insurmountable (see proposition 2). The *Brain and Learning Committee's* first general recommendation for the future was therefore, that a real effort be made to tackle the issue of communication so

that contention between the disciplines and 'fighting for funding' be avoided. As stated in the abovementioned *OECD* report, *trans-disciplinary cooperation* is the way forward. The committee proposed that further development in this area be coordinated by a multi-disciplinary steering committee.

The committee also recommended that steps be taken to improve collaboration between scientists and educators. Specifically, this refers to collaboration between scientists working on the NWO activities, and the educational institutions and educators working under the guidance of the Dutch Ministry of Education, Culture and Science. The research being conducted under the auspices of the NWO is undeniably important, but a real step forwards can only be taken if there is an opportunity to really cooperate with educators and practitioners. As a result, policy issues in the area of educational development will benefit also from assessment by fundamental and applied scientists who are affiliated with NWO.

Last but not least, the committee submitted the *Brain, Learning & Education* project to NWO for consideration as a possible focal point in the *Cognition 2006-2010* programme. The project potentially has major social implications and satisfies a number of important basic conditions, which qualify it for a longer period of focus. There is, for instance, a substantial knowledge base consisting of sound scientific brain and cognition research, as well as considerable interest in this knowledge by educators and practitioners. In the course of 2006, the *Brain, Learning & Education* theme was indeed incorporated into the NWO *Brain & Cognition* theme as part of the 'The Learning Mind' topic, which together with 'The Healthy Mind' and 'The Working Mind' forms the latter's three core topics (see www.nwo.nl).

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The *Netherlands Organisation for Scientific Research (NWO)* set up the *Brain and Learning Committee* in consultation with the *Dutch Ministry of Education, Culture and Science*. The ministry's involvement underlines the significance that it attributes to this development. The participants in the invitational conference (see Appendix for names, interests and affiliations) devoted a considerable amount of time to preparing for the conference and compiling the opinions and arguments that resulted in this report. We thank them most sincerely for their contributions, which enabled the committee to formulate well-founded propositions for the future of the *Brain, Learning & Education* theme.

On behalf of the *Brain and Learning Committee*,

Prof. J. Jolles,
Chair

February 2005/November 2006

RECENT PUBLICATIONS ON THE BRAIN, LEARNING & EDUCATION THEME

Note: the papers marked by * give a recent overview of the most important issues with regard to the theme and are recommended

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