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Ralph Schumacher

The Brain Is Not Enough

Potentials and Limits in Integrating Neuroscience and Pedagogy

Abstract: The desire for founding educational reform on a sound empirical basis has coincided with a period of impressive progress in the field of neuroscience and wide public interest in its findings, leading to an ongoing debate about the potential of neuroscience to inform education reform. But is neuroscience really suited to provide specific instructions for improving learning conditions at school? This paper explores the educational implications of neuroscience.

0. Introduction

Thanks to the ongoing progress in the field of neuroscience we now have more comprehensive insights into human learning and development than we had a decade ago. Imaging methods can shed light on differences in the brain states of humans with regular and irregular trajectories of learning and development. For instance, insights into brain functioning of students who suffer from dyslexia or dyscalculia have helped us to understand why sometimes regular educational efforts may fail (Goswami 2004). The identification of this kind of brain-based constraints in learning through education has initiated an ongoing debate on whether neuroscience in general can inform policy makers and teachers about educational reform and classroom practice. While some authors have outlined plans for integrating research on education and neuroscience (Ansari/Coch 2006; Blakemore/Frith 2005), others have scaled down unrealistic expectations (Bruer 1997, 2002; Goswami 2005) and are concerned that more applicable behavioural research on improving learning opportunities at school is ignored (Stern 2005). I will go beyond such concerns by presenting reasons to emphasize that neuroscience, in principle, cannot provide the specific knowledge required for planning educational environments. The first part of this paper presents an argument for the claim that psychological explanations cannot be reduced to neuroscientific explanations. The second part deals with certain developmental cognitive and learning deficits like, e.g., dyslexia to illustrate the significance of neuroscience for psychological and pedagogical research on learning and instruction. Neuroscientific research on such deficits is of psychological and pedagogical importance because it reveals similarities and differences that are not observable at the level of behaviour. The third part focuses on the difference between biologically privileged learning processes and learning at school. Since psychological and cultural concepts are indispensable to describe the knowledge preconditions for learning at school, neuroscience is, in principle, underdetermined with regard to learning conditions at school.

1. The Irreducibility of Psychological Explanations

Although nobody would call into question that mental states have to be realized by brain states, psychological concepts cannot be reduced to neuroscientific concepts. This is due to the fact that these concepts belong to different and autonomous levels of explanation which are characterized by specific kinds of entities as well as by specific methods and explanatory aims. Whereas at the neuroscientific level we look for causal explanations for the occurrence of brain states, at the psychological level we look for intentions and beliefs to explain behaviour in cognitive terms. As an illustration of the irreducibility of cognitive concepts, let us consider an example from developmental psychology.

The current research of Stephanie Carlson (2005) and her colleagues on executive function and symbolic representation in preschool children is a good example for emphasizing the central explanatory role of irreducible cognitive concepts in psychological theories of cognitive development. Carlson and her colleagues examined the role of symbol systems in the development of executive control over thought and action. Hence, a key requirement for successful inhibition is to direct attention away from the salient perceptual features of a stimulus that tend to elicit a prepotent response. What makes mental disengagement possible? Carlson and her colleagues suggest that symbolic representation is central to this capacity. Abstract symbols, they argue, provide a distance from "the bondage of direct sense perception", thus allowing for self-reflection and adaptive behaviour. Reframing a self-control task in a symbolic context should, thus, systematically influence children's performance, i.e., performance should improve with increasingly distant symbolic stimuli.

Carlson and her colleagues used a conflict task requiring children to suppress a dominant response and initiate a conflicting response. On this task, called 'Less Is More', children had to point to a smaller reward (two candies) to receive a larger reward (five candies). They found that abstract quantity symbols significantly increased the probability of an optimal response. Hence, Carlson and her colleagues came to the conclusion that the degree of symbolic distancing from real treats had a systematic effect on children's ability to choose the smaller reward.

In this explanation, the *degree of abstractness* of symbolic representations plays a crucial role: the more abstract the symbolic representations, the higher the probability of an optimal response on the conflict task. In this particular study, the symbol of a mouse and the symbol of an elephant were the most abstract representations of different quantities of candies. It is important to note that being an abstract representation is not an intrinsic, but a *relational* property. It entirely depends on what the symbol is supposed to stand for. If the symbols of a mouse and of an elephant are used to represent different amounts of candies, they might be regarded as abstract representations. But if these symbols were used to represent mice or elephants, respectively, they could no longer be adequately regarded as abstract representations. Therefore, whether or not a symbol is an abstract representation depends on the objects the symbol is supposed to represent, i.e., on its content. The contents of representations, however, cannot be described in terms of neuroscience because *in order to capture these contents, descriptions have to go beyond the human brain, i.e., they have to take into account external factors like the relations between the symbols and the objects they represent*. Thus, no matter how far neuroscience advances, it will never be able to account for the difference between abstract and concrete representations. Consequently, the concept of the degree of abstractness of representations is a cognitive category that, in principle, cannot be reduced to neuroscientific concepts. Psychological explanations that rely upon this concept are thus irreducible to neuroscientific explanations.

2. The Significance of Neuroscientific Studies for Psychology and Pedagogy

Cognitive states and processes are always realised by states and processes in the brain. For this reason, it is possible to derive certain explanations and instructions from neuroscientific investigations which have a bearing on psychological and pedagogical issues. This holds particularly true for the diagnosis and explanation of developmental cognitive and learning deficits. In this section, six different cases will be presented as an illustration of the psychological and pedagogical importance of neuroscientific studies.

(1) Neuroscientific Explanations of Developmental Cognitive Deficits
Neuroscientific studies can provide novel explanations for phenomena which are already well-known at the psychological level. A current example is a study by Judy DeLoache (2004) who investigated the inability of 18- to 30-month-old infants to identify small models of chairs, slides, cars, etc. as *small models* and to act accordingly. DeLoache related the toddlers' inability to neuroscientific evidence that visual information is processed in two distinct systems in the brain, i.e. in the ventral and in the dorsal system, which are not sufficiently connected at this stage of their cognitive development.

(2) Neuroscientific Explanations of Cognitive and Learning Deficits
Neuroscientific studies can provide explanations of cognitive and learning deficits. This may again be illustrated by the example of dyslexia. Most dyslexic children suffer from impaired phonological awareness. This means, they have difficulties in recognising and producing compound speech sounds in words. Children with these phonological deficits usually have less neuronal activity in temperoparietal areas whilst working on tasks that require them to decide whether certain letters and syllables will rhyme (see, e.g., Simos et al. 2002). Since activation in these areas increases with improving reading ability, dyslexia may be explained

by diminished brain activity in these particular areas (see also Shaywitz et al. 2002). Hence, neuroscientific studies may be of psychological and pedagogical importance because they can provide evidence for the neuronal causes of certain cognitive and learning deficits. It has been shown, for instance, that dyslexia is not due to a *deviate* development of the phonological system. Instead, it is rather caused by a *delayed* development of this system (Goswami 2004). Since delayed development may require treatments that are different from those addressing deviate development, such neuroscientific insights may also help to find the adequate treatment for cognitive and learning deficits.

(3) Different Causes of Cognitive and Learning Deficits
A given cognitive and learning deficit can have different neuronal causes. While no differences are observable at the behavioural level, neuroscientific studies may identify different neuronal causes of a particular cognitive and learning deficit in different individuals. This is again the case with dyslexia, which may be due to both, disorders in the visual or in the auditory system. Accordingly, different treatments have to be applied in these different cases to remediate this cognitive and learning deficit. In this way, neuroscientific studies may have practical consequences for treatment, even though they do not give us detailed information about the specific kinds of treatment which are required to remediate a specific cognitive and learning deficit. Instead, we just learn from such studies that *different* treatments have to be applied.

(4) Early Diagnosis of Cognitive Developmental Disorders by Means of Neuroscientific Evidence
It may in principle be possible to diagnose cognitive developmental disorders by means of neuroscientific evidence before they become salient at the behavioural level. This would imply that there is clear evidence for a reliable relationship between certain brain states at a given developmental stage and the later emergence of specific cognitive developmental disorders. At present, however, neuroscientific methods do not allow for this kind of reliable early diagnosis of cognitive developmental disorders at the *individual level.*

(5) Choice Between Competing Psychological Explanations
Neuroscientific evidence may be referred to for finding out which one of two competing psychological explanations is the more adequate. For instance, if theory A explains dyslexia by disorders in visual perception whereas theory B explains the same cognitive deficit by disorders in language comprehension, neuroscientific research on the respective brain areas may help to determine which of these theories is the best explanation (Goswami 2004).

(6) Training of Precursor Skills
Neuroscientific investigations have shown that brain areas which are activated during adults' mathematical reasoning are also activated during children's finger counting (Dehaene 1997). This finding is consistent with the assumption that finger counting is a mathematical precursor skill the promotion of which may be beneficial for later competence acquisition. If this prediction were confirmed in longitudinal training studies, neuroscientific insights could provide information about the design of instruction in educational settings.

These six examples illustrate that neuroscientific investigations actually are of relevance for psychological and pedagogical explanations because they can reveal similarities and differences that are not observable at the behavioural level. However, it must be kept in mind that this is subject to the condition that empirical evidence is provided for the association between cognitive performance and certain brain states so that the presence of a specific neuronal state can be regarded as the precondition for a specific cognitive ability. Therefore, it must be ruled out that the cognitive abilities in question can also emerge without the respective brain states. Furthermore, it is important to keep in mind that the aforementioned examples mainly refer to the diagnosis and explanation of developmental cognitive and learning deficits. Even though neuroscience is definitely capable of diagnosing and explaining *pathological cases*, one must not jump to the conclusion that it holds similar competences regarding the design of regular learning opportunities at school. In addition, neuroscientific investigations do not tell us anything about the specific content of treatments and trainings to remediate cognitive and learning deficits. They tell us something about the neurological conditions under which certain cognitive abilities are absent and, thus, provide some information about *when* treatments are needed. But they do not provide specific information about *what* exactly has to be done in order to remediate these deficits. In contrast, how such treatments should be designed can only be elaborated in the framework of psychological and pedagogical theories.

This even holds true if neuroscientific studies succeed in identifying specific brain areas activated during certain tasks like, for instance, finger counting. The simple finding that finger counting in children activates brain areas which are associated with mathematical reasoning in adults (Dehaene 1997) does not necessarily lead to the conclusion that later mathematical performance can be deliberately improved by practising finger counting in childhood. Likewise, the fact that our hands are used for eating and writing does not necessarily entail the conclusion that eating is a deliberate training for writing. *It is crucial to note that the fact that the same physiological bases will contribute to the emergence of two competencies is not sufficient for drawing conclusions about treatments or trainings to improve these competencies.* In particular, with respect to the development of mathematical reasoning it may be assumed that this competence essentially depends on additional cultural variables not considered in the description of the human brain. In the following section, I am going to analyse these cultural factors, arguing that neuroscientific studies are in principle too underdetermined to provide specific instructions for the improvement of learning opportunities at school.

3. The Underdetermination of Neuroscience with Regard to Learning at School

Addressing questions of what would be the optimal design of learning opportunities at school, it is important to note that in this context the human brain is only part of a larger system. This part is, of course, indispensable. But as it represents only one factor in a much larger cultural context, its description cannot cover all aspects that are relevant for improving learning opportunities at school.

This is due to the fact that instruction at school concerns the acquisition of knowledge for which *biologically privileged learning* can rarely be expected. Biologically privileged learning occurs if biological programmes determine which learning processes are initiated by which environmental influences, at which developmental stage, and taking which way of execution. Speech as well as many motor skills like, for instance, walking are learned in this way. However, in *cultural learning,* the factors which initiate learning processes, and the course these learning processes will take, are not biologically determined. This distinction between biologically privileged learning and cultural learning corresponds to the differentiation between ,fast route learning' and ,slow route learning' suggested by Uta Frith (2001). While in fast route learning, learning processes are controlled by specific biological ,start-up mechanisms', slow route learning follows more general learning principles. The evolutionary psychologist David Geary (1996) describes the same phenomenon in terms of ,primary and secondary abilities'. It is important to note that cultural learning concerns all contents and abilities that are taught at school—such as reading, writing, and mathematics. Evolution has not prepared our brain for the acquisition of these contents and abilities because these cultural skills have—in an evolutionary perspective—only very recently come into existence. Whereas the brain of *homo sapiens* has already existed for roughly 40.000 years, scripture was invented only about six thousand years ago, and the discovery of the mathematical principles nowadays taught at school occurred a mere three or four centuries ago. *As a consequence, the description of the preconditions for this type of learning has to go far beyond descriptions of the preconditions to be met by the human brain. In addition, further external, i.e., cultural factors which are relevant for successful cultural learning have to be taken into consideration.*

The preconditions for cultural learning are primarily *knowledge preconditions.* For instance, in order to acquire the physical concept of density, children already have to know other physical concepts like weight and volume. This also holds true for the explanation that whales are not fish but mammals. In order to understand that animals are not classified according to their habitat but according to their type of reproduction, children must already have acquired the right kind of knowledge about reproduction in animals. *Since it is not possible to reduce cognitive concepts to neuroscientific concepts, the description of such knowledge preconditions is also irreducible to descriptions of neurological states. Thus, cognitive concepts are indispensable to describe these knowledge preconditions.*

A further important prerequisite for cultural learning is that the respective knowledge base is well-organised. The organization of knowledge plays an eminent role in the explanation of expertise (Chi, in press). In order to understand how experts perform and why they are more capable than non-experts, we must understand how their knowledge is organized, and how their representations might differ from those of novices. For instance, it was found that commercial fishermen sorted marine creatures according to commercial, ecological, or behavioural factors, whereas undergraduates sorted them according to the creatures' appearance. Thus, novices are more likely to base their classifications on surface features, whereas experts are more likely to base their classifications on deeper principles that would be relevant for solving problems. Due to the better organization of their knowledge, experts also have more efficient strategies than novices for integrating new information into their knowledge base.

What a well-organised knowledge base is can only be explained with reference to the specific demands and goals that are assigned to a person because the property of being well-organised is not an intrinsic property of a knowledge base. In contrast, it rather is a *relational* property which can only be assigned if the demands and goals in relation to which the knowledge base should be regarded as being well-organised are specifically stated. It is crucial that the terminology required to describe such demands and goals cannot be reduced to neuroscientific concepts because these demands and goals are *cultural factors outside our brains*. For example, the description of the demands and learning goals which are characteristic for understanding the magnification of binoculars has to refer to scientific concepts and formulas of the laws of optics. Hence, for a knowledge base to be qualified as well-organized, mere neuroscientific criteria will not do. No matter how far neuroscience advances, it will never be able to account for the quality of the organisation of a knowledge base. Consequently, we need cognitive concepts to be able to describe the learning goals, for instance, we have to refer to in order to qualify the organisation of a person's knowledge.

The significance of such cultural factors for cultural learning may be illustrated by the following analogy: What do I have to know to win a regatta? First of all I have to know the physical properties of my sailing boat—for instance, its draught and the size of its keel—to predict its behaviour under certain wind and water conditions. Without this knowledge I cannot predict whether it will be possible for me to steer the boat through a shallow part of the lake. However, for successful participation in a regatta, I also need additional knowledge about the traffic rules in sailing, for example about the right of way, as well as knowledge about strategies for successful sailing and about the intentions, strategies and skills of my competitors. These additional requirements represent knowledge that cannot be reduced to knowledge about the physical properties of my sailing boat because this knowledge refers to factors *outside* my boat.

Just as the sailing boat in the regatta is one factor in a larger cultural context, the brain is just one factor in a larger cultural context with regard to the preconditions for cultural learning. Moreover, just as knowledge about the physical properties of a sailing boat is not sufficient to provide instructions about successful participation in a regatta, mere neuroscientific knowledge about the human brain is also not sufficient to provide specific instructions for improving learning opportunities at school. With respect to these instructions, both kinds of knowledge—physical and neuroscientific—are *principally underdetermined.* However, this does not diminish the general importance of neuroscience—just as the importance of physics is not diminished by the fact that it cannot provide strategies for successful sailing. This underdetermination is rather an expression of the fundamental autonomy of distinct levels of explanation.

The particular strength of neuroscience is its competence to reveal psychologically relevant similarities and differences that are not observable at the level of behaviour. For instance, as already described, neuroscientific investigations have shown that brain areas activated during adults' mathematical reasoning are also activated during children's finger counting (Dehaene 1997). This finding is consistent with the hypothesis that finger counting is a mathematical precursor skill the promotion of which may be beneficial for later competence acquisition. If this hypothesis was confirmed in longitudinal training studies, neuroscientific insights, supplemented by psychological research, could contribute to the design of instruction in educational settings. In addition, it may be possible, in the future, to observe changes occurring in brain organisation during learning processes before any such changes can be observed at the behavioural level. This would lead to a better understanding of the neurological mechanisms underlying these learning processes and might even provide biological markers for developmental disorders like dyslexia and dyscalculia, thus allowing for earlier intervention. Therefore, instead of using neuroscience as a basis for speculations about principles of so-called brain-based education, it should rather be used to contribute to interdisciplinary collaboration on learning and instruction by revealing characteristics of the learning brain that are not observable at the level of behaviour.

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