The Cultural Values of Science
Pontifical Academy of Sciences, *Scripta Varia* 105, Vatican City 2003
www.pas.va/content/dam/accademia/pdf/sv105/sv105-singer.pdf

THE IMPACT OF NEUROSCIENCE ON CULTURE

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The natural sciences share numerous features with human activities that are commonly addressed as cultural. The essence of science is to explore the world around us and ourselves with rational tools. In the center of scientific endeavours is the search for regularities in nature and the formulation of rules. This then permits the construction of predictive models and thereby the foundation of novel views on our conditions. At their roots scientific activities do not differ from those in art, literature and philosophy as the creative process is likely to rely on very similar cognitive functions. The directly perceived world as it is conveyed by our unprotected senses is extended by descriptions of newly uncovered relations, by the formulation of rules, by metaphorical descriptions, and by the creation of artefacts: useful tools in the case of science, metaphorical descriptions of our conditions in the case of art and literature, and rational constructs in the case of philosophy. As all other cultural activities, science changes our view of the world and of ourselves.

Among the various scientific disciplines neuroscience is the one that has with all likelihood the strongest impact on our self-understanding because it explores the organ that is constitutive for the specific qualities of human beings. It is the organ that determines our cognitive abilities and endows us with a mental and spiritual domain.

Before exploring in more detail the consequences of neurobiological discoveries for our self-understanding it is necessary to raise awareness for an important epistemic caveat. In case of brain research, the explanandum and the explanans are identical. A cognitive system, our brain, uses its perceptual and analytical tools in order to describe itself. It is unknown whether this process can converge to a comprehensive description or whether it is susceptible to infinite regress. Another and closely related epistemic problem is that we can only discover what we can imagine, we can only know about us and our conditions what our cognitive abilities allow us to perceive and analyse. Evidence indicates, however, that our cognitive abilities must be confined because our brain is the product of an evolutionary process that has probably not been optimised to bring forth a cognitive system that is endowed with the capacity to perceive and imagine all the dimensions that lie behind the phenomena to which we have access.

It has surely not been the goal of evolution to bring forth a cognitive system that is capable of accessing absolute truth in the Kantian sense. Rather, nervous systems have been optimised by selection pressure to arrive at fast, well adapted, and hence usually pragmatic solutions to real-world problems, problems that organisms are confronted with that occupy a narrow range within the large dimensions spanned by the reality that we know of. Living organisms typically have dimensions in the range between micrometers and meters and hence have adapted to the dynamics that govern interactions among objects at this scale. Accordingly, our sense organs are tuned to decode signals from the environment only within a very narrow range.

Numerous examples of perceptual illusions document that our cognitive systems are not optimised to decode signals from the environment as they would be decoded by a physical measurement device and that our way to categorise phenomena is highly idiosyncratic. The perceived colour of an object is only loosely correlated with the wavelength of the light reflected from a coloured surface but depends essentially on comparison with the spectral composition of light reflected from adjacent surfaces. Electromagnetic waves are perceived as light within a narrow spectral range. If the wavelength exceeds the visible range we perceive the radiation as heat. Likewise, low frequency mechanical waves are perceived as vibrations and higher frequency waves as sounds. Also, the way in which we make inferences and construct predictive models orients itself on the typical dynamics that dominate interactions among objects that have our dimensions. This is probably one of the reasons why classical physics has preceded quantum physics.

Another result of evolutionary adaptation is our inclination to assume linearity when formulating predictive models about the dynamics of our environment. We have difficulties to imagine non-linear processes – and there is a good reason for this. As it is difficult and in the long run impossible to predict the trajectories of highly non-linear dynamic systems there was no evolutionary pressure to develop an intuitive understanding of such dynamics. Hence, our cognitive abilities have been optimised to analyse those processes which permit good predictions on future trajectories, and these are processes with linear dynamics.

Can these restrictions and idiosyncrasies of our cognitive functions be overcome by reasoning? The fact that we became aware of these restrictions and of the sometimes illusionary nature of our perceptions proves that reasoning and the design of physical tools can compensate for some of the deficiencies of our cognition. Likewise, the ability to find mathematical tools for the treatment of non-linear dynamic processes and for the description of interactions in the quantum world documents that we can extend our imagination by tools based on reasoning. However, the neuronal substrate that endows us with the ability to reason is the same as that which underlies our perceptual abilities. It is the cerebral cortex. The regions of the cerebral cortex that support reasoning are not different from those that mediate our perceptions and they owe their properties to the same evolutionary process. Hence, it needs to be considered that our reasoning is also constrained by the same evolutionary demands that shaped our perceptual systems. It is likely, therefore, that the nature of our reasoning is also idiosyncratic and optimised according to rather pragmatic evolutionary criteria.

Perhaps it is these deficiencies of our cognitive abilities which are at the basis of the incompatibilities among the various description systems that mankind has developed about itself and the embedding world. The most blatant of these incompatibilities are apparent in the descriptions that we derive from introspection on the one hand and from scientific analysis of our conditions on the other. The self-model that we have derived from our first person perspective is by and large incompatible with the descriptions that we derive from a third person perspective on which our scientific inquiries are based. We experience ourselves as self-determined autonomous agents that are endowed with free will, with a mental and a spiritual dimension, and it is our intuition that processes in this mental domain precede and dominate the physical processes that underlie our actions. However, when we analyse our conditions from the scientific third person perspective, we are forced to view ourselves as organisms that own their existence to a continuous evolutionary processes, the rules of which can be formulated within physico-chemical description systems. Likewise, it appears to us that we can describe in the same terms the ontogeny of human beings from the egg to the adult organism. Although this process is exceedingly complex we seem to be able to understand it as a self-organising process that will eventually be describable within the description systems of the natural sciences.

Obviously, human beings are distinct from animals because they have a cultural dimension. However, this dimension, too, appears to us as a product of evolution, as a product of the constructive and creative cognitive interactions among beings who are endowed with brains that have the abilities to create mental, cultural and spiritual dimensions. Among these abilities are our capacity to develop a theory of mind – to imagine what goes on in the brain of the respective other when he/she is exposed to a particular condition – the ability to develop a symbolic language system, and the capacity to form meta-representations of one's own brain states, i.e. to be aware of one's perceptions, thoughts and actions. An analysis of the neuronal prerequisites for the evolution of human culture is another and fascinating endeavour of contemporary anthropology and cannot be dealt with in the frame of this contribution. Rather, an attempt will be made to explore to which extent the incompatibilities between first person and third person perspectives can be resolved on the basis of currently available knowledge about the relations between brain functions and behaviour.

We seem to have no difficulties to understand the behaviour of animals as an emergent property of the neuronal interactions in their nervous systems. Also, we seem to have no problem with the concept that the emergent behaviour is described in a different description system as the neuronal processes which generate this behaviour. We are used to the fact that the emergent properties of complex systems are not identical with the components whose interactions generate these properties although they are fully determined by the component interactions. However, we seem to encounter insurmountable problems when this notion is generalised to higher brain functions that are specific for human beings. These functions comprise our abilities to perceive, to decide, to imagine, to plan, and to execute intentional acts, and above all, our capacity to be aware of all these functions. This is the more surprising as we have indisputable evidence that all of these higher cognitive functions are emergent properties of the neuronal interactions in the brain. Partly, this evidence comes from investigations of the relation between brain functions and behaviour in animals. Many of the cognitive abilities listed above can also be identified in higher mammals, and here direct correlations can be established with the underlying neuronal processes. Similarly compelling evidence for such substrate-function relations has also been obtained for the human brain with the help of non-invasive imaging techniques that allow measurements of neuronal activity while human subjects perform cognitive tasks. These studies establish close correlations between the activation of particular brain regions and both cognitive and executive functions. It is now possible to specify which brain regions become active when human subjects imagine perceptual objects, when they direct attention to particular contents, when they plan to execute a particular action, when they reason, when they have particular emotions, and when they are subject to self-generated delusions such as occur for example during hallucinations or déjà-vu experiences.

Comparative studies of the brains of different species have also provided indisputable evidence that the higher cognitive functions that we consider to be specific for human beings are the result of a continuous increase in the complexity of the nervous system that has been achieved during evolution. We see no events in the evolution of the brain that would justify identification of ontological discontinuities, neither at the structural nor at the functional level. Progress in molecular biology and physiology leaves no doubt that the properties of nerve cells have changed only little from their first appearance in molluscs until their implementation in the cerebral cortex of primates. All the mechanisms of signal transduction within cells as well as between cells are conserved. Also, since the appearance of the vertebrate brain, the basic organisation of the nervous system has remained unchanged. The only major change is the steady increase of the surface of the cerebral cortex and of the volume of related structures such as the basal ganglia and the cerebellum. Remarkable in this context is the fact that the new areas of the cerebral cortex, that have been added in the course of evolution, have exactly the same intrinsic organisation as the phylogenetically older areas. Since the computational algorithms realised by neuronal networks depend exclusively on the functional architecture of the respective network, it can be inferred that the more recently implemented cortical areas operate according to exactly the same principles as the older regions. This forces the conclusion that the emergence of higher cognitive functions is solely due to the iteration of self-similar computational operations. Considering the embedding of the newly developed cortical areas it is of importance to note that these are receiving their input mainly from the already existing areas rather than from the sensory periphery. Likewise, their output is not directly connected to effector organs but to phylogenetically older cortical areas which have executive functions. Thus, the newly added cortical areas receive already pre-processed information and appear to treat this information in very much the same way as the older areas process the information that arrives from the sense organs. The hypothesis is that this iteration of self-similar computational operations leads to the generation of ever more abstract and symbolic descriptions. Because the newly added areas are also massively and reciprocally interconnected with each other, the higher order descriptions realised by these areas are also no longer confined by boundaries between the different sensory modalities. This is the structural basis for our ability to generate abstract, modality-independent representations of contents. On the one hand, such an organisation is probably at the basis of our ability to develop a language based on abstract symbols, on the other hand it can probably account for the generation of meta-representations which allow the brain to run a protocol of its own internal processes. At least intuitively it appears plausible that such an iteration of self-similar representational processes enables highly evolved brains to subject part of their own functions to cognitive processes, and hence become aware of their own perceptual and executive acts.

In a highly simplified way one could say that the phylogenetically more recent cortical areas look on the already existing areas that are directly connected with the sensory and motor periphery as these look at the outer world. Thus, brain processes become themselves the subject of cognitive operations. This could be the organisational basis of a function that is sometimes addressed as the 'inner eye'. However, this simplistic view leaves one with the unresolved problem of who then looks at the representations of these internal processes, interprets them in a coherent way, reaches decisions, and executes adapted responses.

The classical view has been that there ought to be a convergence center somewhere in the brain where all the available information converges and is available at the same time so that coherent interpretations of the world become possible. This would be the place where decisions are reached, plans formulated, actions coordinated, and finally it would have to be the place where the self articulates itself.

Neurobiological evidence indicates that this intuition is wrong. The brain presents itself as a highly distributed system in which a large number of computational operations occur simultaneously. There is no evidence whatsoever for the existence of a coordinating center at the top of the processing hierarchy. This suggests that the neuronal substrates of a percept, of a decision, of an action plan, and of a motor program, are specific spatio-temporal patterns of widely distributed neuronal responses. The same must be true for the meta-representations that contain the contents of phenomenal awareness, the consciously experienced qualia. Therefore, it is a major challenge of contemporary neuroscience to identify the binding mechanisms that coordinate the distributed activities into functionally coherent assemblies. A mechanism is required that defines from moment to moment which neuronal responses need to be related to each other, and read-out processes are required which are capable of identifying distributed dynamic states as representing particular contents.

Much of our recent work in the laboratory in Frankfurt has been devoted to the identification of putative binding mechanisms and to decipher the nature of the distributed code. Our hypothesis is that temporal coherence, i.e. the synchronisation of oscillatory responses, serves as signature of relatedness that binds together in a context-dependent and highly dynamic way the responses of large numbers of spatially distributed neurones. This is not the place to present and discuss the results of the related experimental work. However, the essential concepts and findings have been summarised in several recent review publications that are listed at the end of this chapter.

In essence, the search for binding mechanisms in distributed processing is accomplished by recording simultaneously from very large numbers of neurones, analysing temporal relations in these high-dimensional time series and then trying to relate specific correlation patterns to perceptual and/or motor performance. The evidence that has been obtained so far is fully compatible with the notion that representations consist of highly complex and dynamic spatio-temporal patterns of neuronal activity that emerge from a self-organising process that assures very precise temporal coordination of the discharge sequences of individual neurones. Thus, it appears as if representations of contents in the cerebral cortex are best described as distributed dynamical states that are configurated by the temporally structured activity of very large numbers of neurones in ever changing constellations.

We are still far from fully understanding the self-organising processes that structure these distributed and dynamic codes, nor do we understand how these dynamic states are identified by the brain as a consistent result of computational operations and how they are distinguished from spurious constellations. Accordingly, we are also far from understanding how these states can give rise to subjective experiences, emotions, and last but not least to consciousness. What is required now is the development of analytical tools for the investigation and characterisation of consistent patterns in these highly complex non-linear, non-stationary dynamics.

At present, it appears as if we knew enough about the components of the brain, the nerve cells, and about the way in which they can interact with each other in order to solve these problems. It is unlikely that we shall have to postulate hitherto undiscovered mechanisms of signal transduction, or that we shall have to include phenomena of non-classical interactions such as occur in the quantum world. The reason for this prediction is that we have no difficulties to fully explain the behaviour of simple organisms by what we know at present about the organisation of their nervous system. As our brain differs from the simple systems only because of dramatically increased complexity it must be assumed that our specific abilities result from the phase transitions that occur in complex non-linear systems and lead to the emergence of new qualities.

If this prediction is correct, we shall eventually arrive at a comprehensive description of brain states that correspond to particular behaviours including mental states associated with perception, decision making, planning, and consciousness. We shall then be able to establish a causal relation between a particular brain state and a particular subjective experience, and this is probably as far as we can get. However, if this prediction holds it necessarily implies that also our subjective experience of having decided something on the basis of subconsciously and consciously represented variables is itself a consequence of dynamic brain processes that preceded this experience. This challenges our intuition that our mental activities including our will to perform particular actions are causing neuronal states rather than being a consequence of them. A particular neuronal state that corresponds to a decision, or an intention, or a judgement is of course not fully determined by preceding states because the brain, like any other dynamical system, is subject to noise. Hence, transitions from one state to the next are not fully determined but follow probabilistic rules. However, this does not counter the notion that our experience or awareness of having decided something is the consequence of neuronal states that preceded this awareness and lead to it. This conclusion seems logically unavoidable but it is entirely incompatible with our traditional notion of free will that is so deeply routed in our culture. This notion assumes a strict dichotomy between the mental and the material world and poses that the mental processes are autonomous and the cause of material processes rather than their consequences. In our case the mental decision to act would have to initiate the neuronal activities that are required to translate the decision into action. In the light of modern neurobiological evidence this concept of mental causation of material processes is untenable, and we therefore have to arrive at a new self-model that reconciles our intuition to be an autonomous agent with our knowledge about our brains. Necessarily, such a synthetic attempt will have far reaching consequences on our self-understanding, on our concepts of responsibility and guilt, and our educational systems. Thus, knowledge provided by neurobiological research will inevitably have a massive impact on dimensions that we consider as genuinely cultural. Science, therefore, needs to be considered as an integral part of cultural activities.

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DISCUSSION ON THE PAPER BY SINGER

ZICHICHI: Professor Singer, in your very interesting and provocative report you emphasised a very important point, oculus imagination, saying that there is nothing that can go beyond our imagination. This is unfortunately not true for the following reason: our oculus imagination fails to imagine what science discovers in the logic of nature. I will give you only two examples. Example number one: no one before 1905 had been able to imagine the existence of a real world, we call it 'space-like'. Our world is 'time-like'; time dominates. This took two hundred years of experiments in electromagnetism to be discovered. Now something more recent. Up to 1947, no one could imagine the existence of the third column of our building blocks. We are made of three columns (the world, including galaxies and everything, including you and me), and four fundamental forces in nature. No one could imagine the existence of the second column up to 1947, and no one could imagine the existence of the third column up to 1960, so oculus imagination has only one distinct feature compared to all other brains which you listed in your evolution picture. Our brain is the only one that is able to understand nature's imagination. Our imagination is very small compared to the imagination of nature.

SINGER: I cannot disagree more. The examples you gave were examples where, due to instrumentation and calculus, you discover new qualities of nature, you get answers to questions that you've asked, because you could imagine these questions.

ZICHICHI: This is not true. The greatest steps in science come from the totally unexpected and unthinkable. I gave you two examples. Let me give a third one. The fundamental force of nature discovered by Fermi, the so-called 'weak force' which controls the nuclear fire of our sun and all the stars. No one could imagine the existence of such a fundamental force of nature. It took fifty years to understand the weak forces, so...

SINGER: I think we should discuss it in private, but it depends on what you understand by understanding and imagining. It just says, and I think this is an inevitable conclusion, that there must be limits to our cognition, because our cognitive tool is the product of an evolutionary process. It would be very, very surprising if there were no limits to the ability of our brains to understand. What do we know? We don't even know the limits. I think the only thing we can safely say is that there must be limits. Now, I called them limits of imagination, you may call them limits of cognition or whatever, let's do this privately.

WHITE: Professor Singer, as you know those humble surgeons like myself that have to operate on this incredible organ you've been discussing, using many of the techniques that you use in your studies to locate centres of function and to avoid areas of importance, and yet we remove large sections of the human brain as you well know, and particularly of the cortex, and so the question I am asking is, why is it that these patients so often recover so very, very well at a mental level and many of them, of course, do not? Is a redundancy built into the system of which you're speaking, is a repair built into the system, or is it that we are still not capable of measuring these people who in some way or other have had, you know, significant brain damage?

SINGER: It doesn't seem as if there were redundancy in the sense that there are areas that are not used and then come into play once you need them, because any lesion always causes deficits. The brain uses itself fully, but it's extremely plastic and it can use strategies to compensate for lost functions, unfortunately, only to some extent. Think about stroke and the inability to recover.

CARDINAL MARTINI: Thank you very much for this fascinating presentation. I have two questions. Maybe you said this, but through the limits of my understanding I could not exactly catch the point. My first question: is it evident that, in our mind, affections, emotions count much more than perceptions and insights? You gave examples of perceptions. But some authors, I am thinking of Gerard Roth, think that emotions are what count, and that what we think are decisions from insights and reasoning are really emotions. Is there any evidence of that? And then the second question: from what you showed, one may think that the system is always working, able to work at the same capacity. How is this reconcilable with the fact that we not only fall asleep, but after ten minutes of attention it goes down, and then it comes again. Is there any evidence in the system for this?

SINGER: One can show very well the state changes which are associated with attention, drowsiness and sleep. Sleep seems to be a very important active process of rearranging conditions in the brain in order to stabilise memories and keep the homeostasis in order, dreaming as well. Now, concerning emotions, it is certainly true that what gets into consciousness is only those contents to which attention is directed, and the emotional background that is permanently changing in the brain biases the focus of attention towards certain contents. When you are hungry, you are much more likely to perceive a bakery shop or to be more sensitive to the smell of food than when you are not hungry, or even feeling bad. So, what we are focusing on is very much determined by these ongoing emotional drives. They control attention, and attention then controls what's coming into consciousness, because most of the factors that determine our actions are unconscious motives that we have no handle on.