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# The cognitive sciences and their method: a physicist's perspective

## Introduction: explaining physics

Every physicist would like to know why is it that he or she can do physics and what it precisely means. The fact that physics constitutes a doable enterprise has been debated mostly by those who show more sensitivity to what physics studies beyond a mere acknowledgement of physics' main task of explaining and predicting natural phenomena by means of physical laws. Physical theories such as quantum mechanics and general theory of relativity are highly successful and there are precise reasons for this state of affairs.[1] Normally, a physicist will have a very good understanding of such mathematical notions as a derivative, an integral or more complex ones such as, e.g., functional spaces and differentiable manifolds. But this does not answer the questions how it is that these ideas can be had by a physicist.

Philosophy yields a spectrum of responses to this matter known as the *problem of the universals*.[2] None of them, however, is satisfactory for each even-

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[1] Cf. E. P. Wigner, *The unreasonable effectiveness of mathematics in the natural sciences*, "Communications on Pure and Applied Mathematics" 1960 no. 13, p. 1–14.

[2] Cf. A. A. Maurer, *Medieval philosophy*, Toronto 1982, p. 61–65. For the analysis of the contemporary revival of the problem of universals see: W.V.O. Quine, *On what there is*, "Review of Metaphysics" 1948 vol. 2, no. 5, pp. 21–38.

tually rests on *a priori* philosophical assumptions. Consequently, much hope is now seen in the cognitive sciences to provide explanations why, for instance, mathematical platonism is such a vivid stance among physicists.[3] The famous case of Roger Penrose is but the best example of a thinker whose theoretical speculation is heavily influenced by the platonic doctrine. In order to justify his claims, Penrose resorts to the notion of *intuition* as a cognitive power involving an immediate insight into an atemporal universe of the mathematical truth.[4] Cognitive sciences, on the other hand, cast serious doubt on the possibility of intuitive knowledge.[5] In sum, a contemporary physicist should demonstrate considerable interest in the progress of cognitive sciences for two reasons: (1) they may shed important light on the process of formulation of physical theories and (2) physical theories are frequently resorted to as one attempts to study mental phenomena (e.g., quantum models of the mind).

Can a physicist offer anything to the cognitive sciences in return? The primary goal of the presented article is to demonstrate why the answer to this question is in positive. A physicist seems to have a somewhat privileged position for he or she exercises a scientific discipline characterized by a most transparent and best analyzed methodology. In brief, the progress of physics always involves the combination of the theoretical prediction with an experiment. Physics brings its fruit when an appropriate mathematical structure is discovered (some say guessed) leading to the explanation of a large class of phenomena and to the prediction of radically new effects. It is precisely the growing importance of cognitive sciences that awakens physicist's methodological instincts and prompts him or her to put the methodological intricacies of cognitive sciences in a physicist's perspective. In particular, two areas of inquiry are singled out: (1) the interdisciplinary character of cognitive sciences and their conceptual basis and (2) the experimental methods in cognitive sciences that have physics as their basis. Reflecting upon these two areas will lead to the better understanding how knowledge is acquired in the cognitive sciences both by means of their theoretical foundations and the experimental evidence.

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3 Cf. B. Davies, *Some recent articles about platonism*, "EMS Newsletter" 2009 no. 64, p. 24–27.

4 R. Penrose, *The road to reality*, New York 2005, p. 7–23; Cf. D. Mumford, *Why I am a platonist*, "EMS Newsletter" 2008 no. 70, p. 27–30.

5 Cf. L. Cosmides, J. Tooby, *Beyond intuition and instinct blindness. Toward an evolutionarily rigorous cognitive science*, "Cognition" 1994 no. 50, p. 41–77.

## Conceptual intricacies of the cognitive sciences

Although physics splits into many sub-disciplines such as classical mechanics, thermodynamics, electrodynamics, quantum field theory, solid state theory and others, it constitutes a well unified body of knowledge. This is achieved by the use of mathematics as its primary method as well as a common conceptual basis that builds into the mathematical equations expressing the physical laws. Such notions as *space*, *time* (more correctly space-time) and *field* lie at the root of each physical theory. Several spectacular unifications have been achieved in physics where disparate theoretical frameworks merged into a generalized scheme. For instance, the unification of Galilean mechanics with the theory of electromagnetism led to the introduction of the notion of *spacetime* in the special theory of relativity thereby revealing the limited character of space and time treated separately. This shows a very important mechanism of the scientific progress where the common sense concepts that have migrated from philosophy to physics lose their applicability as the theory needs to explain a larger class of phenomena. In particular, the notions of space and time in the special relativity theory can be considered to be *phenomenological (emergent)* for velocities small compared to the velocity of light. Similarly, it is expected that the notion of spacetime might disappear entirely in the theory of quantum gravity and that spacetime will only emerge in the low energy limit.[6]

As a physicist turns the attention to the cognitive sciences, he or she immediately notices the diverse conceptual bases of the contributing disciplines. This is typical for an interdisciplinary field of study. Inasmuch as the different branches of physics rely to a considerable degree on a common conceptual basis, the different components of the cognitive sciences seem to be speaking conceptually disjoint languages. The MIT Encyclopedia of Cognitive Sciences names a range the contributing disciplines that include: (1) philosophy of mind, (2) neuroscience, (3) linguistic studies, (4) cultural studies, (5) psychology and (6) computational intelligence.[7] Such a situation calls for an in-depth methodological analysis for the evident interdisciplinary character of the cognitive sciences makes the justification of its inferences a bit more complex as it is in physics.

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[6] J. Butterfield, C. Isham, *Spacetime and the philosophical challenge of quantum gravity*, [in:] *Physics meets philosophy at the planck scale*, ed. C. Callender, N. Huggett, Cambridge, MA 2001, p. 33–89.

[7] *The MIT encyclopedia of the cognitive sciences*, ed. R. A. Wilson, F. C. Keil, Cambridge, MA 1999.

Literature offers several valuable studies that undertake the effort to clarify the relations between the contributing disciplines within the cognitive sciences.[8] Most naturally, this is achieved in the perspective of the so called *philosophy in science* program pioneered by Michael Heller.[9] Although the content of the cognitive sciences specified above includes philosophy on the same footing with others, the philosophy in science program permits to reveal a structure of relationships that occur between the different disciplines. The program has been shown to be extremely fruitful in physics as it allowed for a deepened understanding of its development with special emphasis on its ties with philosophy, especially in regards to the exchange and refinement of some common sense notions operative in the philosophical discourse. This process was illustrated above with the notion of *space-time* as the primary example.

The authors of the publications referred to above, namely, Wojciech Grygiel, Łukasz Kurek and Bartosz Brożek, present different attempts to locate the enterprise of the cognitive sciences in the perspective of the philosophy of science program. Although the main starting point is the original tripartite relation between philosophy and science, the authors diverge in their focus on the range of the contributing disciplines that they wish to reflect upon. In my article, I concentrated on the cognitive sciences in their entire complexity and I proceeded to map out in more detail the relation between philosophy and the other disciplines as it is proper for the method of philosophy in physics. Interestingly enough, it turns out that similarly to physics, philosophy of mind understood as the pre-scientific legacy of the efforts to understand mind and its cognitive powers (e.g., folk psychology or epistemology), carries with it most of the vital questions that are studied by the strictly scientific branches of the cognitive sciences. These include sensation, emotions, qualia, free will, consciousness, abstract thinking, formation of concepts and many others.

It must be remembered, however, that philosophy of mind thus understood heavily relies on the strictly philosophical stance of the *mind-body dualism*. The body is the material substance of the brain while the mind is an immaterial entity responsible for the cognitive functions such as reason and free

[8] W. P. Grygiel, *Metodologiczne aspekty uprawiania filozofii umysłu w kontekście nauk kognitywnych*, [in:] *Oblicza racjonalności. Wokół myśli Michała Hellera*, red. B. Brożek, J. Mączka, W. P. Grygiel, M. L. Hohol, Kraków 2011, p. 51–62; Ł. Kurek, *Neurofilozofia jako filozofia w kontekście nauki*, [in:] *Oblicza racjonalności*, op. cit., p. 63–82; B. Brożek, *Philosophy in neuroscience*, [in:] *Philosophy in science. Methods and applications*, ed. B. Brożek, J. Mączka, W. P. Grygiel, Kraków 2011, p. 163–182.

[9] M. Heller, *How is philosophy in science possibile?*, [in:] *Philosophy in science*, op. cit., p. 13–24.

will. Contemporary neuroscience, on the other hand, does not support the mind-body dualism as it demonstrates that many of the cognitive functions normally thought of as proper to the activity of the immaterial mind are functions exercised by the material tissue of the brain.[10] This position bears the name of *functionalism*. Although I did not specifically elaborate on this point, the demise of the mind-body dualism in the cognitive sciences is somewhat reminiscent of the non-applicability of the Aristotelian matter/form distinction in physics. Clearly then, in both cases an *a priori* philosophical standpoint gives in as the natural sciences yield their precise explanations of the workings of the nature.

The differences between philosophizing in the context of physics and the cognitive sciences become more transparent as one considers the migration of notions between philosophy and the disciplines that contribute to the cognitive sciences. Due to their interdisciplinary character, the cognitive sciences comprise a variety of fields of study with their discourse being shaped by concepts of varying proximity to philosophy. As it has been already mentioned, physics did naturally absorb many philosophical notions and, by adjusting their content, made them fitting to be engaged in formalized physical theories. This is not uniformly the case in the cognitive sciences. At some point I state the following:

> Inasmuch as the concepts used in psychology, cultural or linguistic studies rely to a considerable degree on the philosophical conceptual framework, neuroscience and the computational intelligence in particular, grow out of distinct paradigms of science and their content is expressed within conceptual bases not rooted in the classical philosophy of mind.[11]

Such a complex situation results in different philosophical notions working their way into the territory of the cognitive sciences with variable success. In the context of the classical (folk) philosophical approach, for instance, the concepts of the *person* and of the *free will* are tightly linked together. It is the human person that wills and its acts are elicited without being caused so that the agent is capable of choosing otherwise without being in any way

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[10] P. S. Churchland, *Brain-wise. Studies in neurophilosophy*, The MIT Press: Cambridge, Massachussets 2002.

[11] W. P. Grygiel, *Metodologiczne aspekty uprawiania filozofii umysłu w kontekście nauk kognitywnych*, [in:] *Oblicza racjonalności*, op. cit., p. 51–62.

pre-determined towards any of the available options. Contemporary cognitive research seems to be contradicting this idealized notion of the free will and it is more consistent with the Humean critics of the free will's absolute indeterminacy. Antonio Damasio clearly demonstrated that the human act of making a choice is conditioned by a complexus of emotional responses thereby blurring the classical understanding of the free will as being the higher level intellectual appetite in relation to the lower level emotive powers (the concept of *somatic markers*).[12] At present, the content of the notion of the free will is evidently being refined to reflect the input of the cognitive sciences. Likewise, according to the analysis put together by Załuski, the classical concept of the person cannot be fully substantiated on the grounds of the biological sciences.[13]

The history of physics suggests that it is not only the case of spacetime but of other previously celebrated notions such as *flogiston* or *ether* that at some point had played an important heuristic role. Ultimately, the progress of science invalidated them as being incapable of explaining newly discovered phenomena. It remains to be seen whether the classical conceptual foundation of the philosophy of mind bears an absolute value or the development of the cognitive sciences will call for a in-depth revision of the classical concepts utilized to understand the nature of mind. Taking into account the importance of these concepts in many areas of the human life (e.g., law, ethics or religion), one can hope that following the case of physics, they will turn out to be *emergent* from a yet unknown more fundamental theory of mind.

In the effort to provide a conceptual link to the classical concepts of the philosophy of mind, the cognitive scientists coined out the term *neuronal correlate*. The philosophical import of this term was pointedly discussed by Łukasz Kurek in the context of the analysis of *neurophilosophy* as philosophy exercised in the context of *neuroscience*. Evidently, Kurek treats the problem of the philosophy of mind as philosophy of science narrowed down to a discipline singled out of the content of the cognitive sciences mentioned above. Similar analysis is offered by Bartosz Brożek with more emphasis on the methodological and structural aspects of neuroscience thereby giving better insight into how one proceeds in putting together a neuroscientific theory. Since in the next section I wish to devote more attention to the precise meaning of the neuroscientific experiments as perceived by a physicist, the inquiry into the meaning of the

[12] A. Damasio, *Descartes' error. Emotion, reason, and the human brain*, New York 1994.

[13] W. Załuski, *Pojęcie osoby w świetle nauk biologicznych*, [in:] *Oblicza racjonalności*, op. cit., p. 83–98.

term *neuronal correlate* provides an opportunity to better explicate the methodological and interpretative issues of what it really is that one obtains as data in such experiments.

If, following Kurek, the definition of the neuronal correlate of consciousness given by Chalmers is used, the *state* of the neuronal correlate is matched with the *state* of consciousness.[14] From the physical point of view, to know a state of a system under study means to know a set of values of physical quantities that yield full information on a system at a given instance of time. It is commonly accepted that the main goal of neuroscience is to seek out the neuronal correlates of consciousness and other mental activities such as free will, emotions or abstract thinking. In other words, one attempts to experimentally match the given mental activity with the excitation of a particular fragment of the neuronal network present in the physically localizable brain tissue. Since the neuroscientific experiments such as fMRI have a strictly physical effect as its basis, the measurement returns the information on an *altered state within the brain tissue* as the mental activity under study occurs. Consequently, to say that a neuronal correlate was found in such manner faces the difficulty of not being able to discriminate among different neuronal correlates yielding potentially the same observable states. The upshot of this discussion is that as one employs any technique in the cognitive sciences that relies on the measurement of physical quantities one gains access to the states of objects that one assumes to cause the observables and not to the object themselves as it is proper to the classical philosophical analysis.

## A cognitive experiment: functional magnetic resonance imaging

Every cognitive scientist realizes that many of the experimental methods commonly used in the cognitive sciences utilize strictly physical effects. Three techniques play the leading role: (1) EEG – electroencephalography, (2) PET – positron emission tomography and (3) fMRI – functional magnetic resonance imaging. Due to fMRI's greatest versatility and image precision, this technique will be discussed as an exemplary one. The technique allows for the study of the brain activation processes so that they can be correlated with the brain's

[14] D. Chalmers, *What is a neural correlate of consciousness?*, [in:] *Neural correlates of consciousness. Empirical and conceptual questions*, ed. T. Metzinger, Cambridge, MA 2000, p. 18.

cognitive functions already adverted to in the previous section.[15] Before the core analysis is carried out, however, a terminological preliminary seems to be in order. The name *functional magnetic resonance imaging* (fMRI) is already a twofold derivative with respect to how it is used originally in physics and chemistry, namely, the *nuclear magnetic resonance* abbreviated as NMR. Firstly, The term *imaging* brings in the fact that by means of a highly sophisticated digital techniques, the experimental response is processed to yield an image of a structural change of the brain's tissue induced by its excitation or a pathological change. The nuclear magnetic resonance technique has gained a tremendous popularity in organic chemistry and biochemistry for the NMR spectra of organic molecules reflect their structure in a very precise way and allow for a straightforward interpretation. Secondly, the term *functional* singles out a very specific one from a variety of imaging techniques that is specifically designed to trace the brain activity through the analysis of the corresponding changes in the blood flow.

The physical theory that governs the fundamental effect in fMRI and in all magnetic resonance techniques is *quantum mechanics*. According to this theory, each nucleus possesses a net spin magnetic moment with degenerate values described by the spin quantum numbers. As a nucleus with a non-zero net magnetic moment is placed in an external magnetic field, the degeneracy is removed and transitions are observed between the different spin states. Any college level textbook can be consulted for further theoretical as well as technical details.[16] What is the most important, however, is that the state splitting pattern as well as some dynamical magnetic properties of the nuclei depends on the symmetry of the external magnetic field. In particular, the corresponding physical parameters of a given nucleus are a precise function of the distribution of the surrounding spin magnetic moments. Consequently, the nuclear magnetic resonance is a technique that permits the study of the environment of selected nuclei by analyzing the splitting pattern produced by an external magnetic field of the surrounding atomic nuclei in a particle of interest.

Inasmuch as physics yields the theoretical basis for NMR, it is chemistry that translates the data into the structure of molecules. This is an important interpretative step for the structure of the magnetic resonance spectral lines

[15] For a solid introduction into the imaging techniques see: *Handbook of functional neuroimaging of cognition*, ed. R. Cabeza, A. Kingstone, Cambridge, MA 2006.

[16] Cf. J. Keeler, *Understanding NMR spectroscopy*, Chichester 2005.

is being mapped into a molecular model where atoms are visualized as balls, bonds as sticks connecting the atoms. Such a model is of little or no importance for a physicist but it is a great heuristic tool for a chemist allowing for the formulation of chemical laws explaining the properties of molecules and the mechanisms of chemical reactions. Although the magnetic resonance effect is generated at the atomic level, its explanative power transfers upon more complex structures of chemical molecules. In other words, the experimental control over the level of single atoms yields information on the emergent structures of molecules whose properties are irreducible to that level. In organic chemistry, for instance, two versions of NMR are most useful for obvious reasons: $^{1}$H-NMR and $^{13}$C-NMR. It is also worth mentioning that the magnetic resonance effects in these techniques operate at distances of approximately 1 nm (10–9 m). Moreover, the size of the molecule water that will be central to the following discussion is slightly more than 1Å (10–10 m).

The interpretative complexity increases considerably as one shifts to the analysis of the magnetic resonance data in neuroscience. As it has been already pointed out, the main aim of such a study is to identify the regions of the brain that become activated as the brain exercises its standard cognitive functions. Indeed, the use of the fMRI as well as other techniques has greatly improved our knowledge of the regions of the brain responsible for these functions. Seeing a color change on the screen of the fMRI as a response to a particular mental activity is surely rewarding, but being able to fully understand the data acquisition process and to properly interpret them calls for an in-depth methodological analysis. The first reason is that the path between applying a magnetic impulse to the brain and stating that "here is where it thinks" is a lot more complex than, for instance, distinguishing between two isomers of an organic compound with the same atomic composition.

In the first approximation, the extent of that path can be ascertained by simply realizing that the resonance effect takes place at the nanometer scale while the fMRI output points to regions of the brain within the range of at least milimeters. This amounts to eight orders of magnitude. Furthermore, the biological structure such as the neuronal tissue of the brain does not as an entity participate in the production of the resonance effect. The fMRI apparatus is tuned in to reflect the changes of the environment of the specific atoms of hydrogen in the molecules of water whereby the technique principally remains the $^{1}$H-NMR with the difference that it is not the absorption spectrum of transitions between the states of nuclei that is measured but a certain relaxation parameter upon the application of the magnetic pulse. Be that as it may, the hydrogen atoms of water serve only as environmental probes to identify a biological activity on a higher level of complexity. Two crucial steps lie in the way between the actual object of interest, that is the brain activity and the proper environment that alters the state of the hydrogen atoms giving the measurable resonance effect (1) the increased brain activity results in the growth of the oxygen demand in the corresponding areas of the brain and (2) the blood the contains more oxygenated hemoglobin has different magnetic properties as compared to that not carrying oxygen. Let us look at these steps in a more detail. The first step linking the brain activity with the consumption of oxygen relies on the well documented research that both the flux as well as the level of the oxygen-enriched blood correlate with the neuronal activity of the brain.[17] The second step takes advantage of the fact that hemoglobin without oxygen (deoxyhemoglobin) is highly *paramagnetic* due to the high spin of the hem's iron while hemoglobin with attached oxygen (oxyhemoglobin) is *diamagnetic* due to its low spin. As the concentration of the deoxyhemoglobin varies in the blood, it causes the change in the spin echo (T2) and the gradient echo (T2*) relaxation times that are in turn picked up by the fMRI instrument. This phenomenon bears the name of BOLD (Blood Oxygenation Level Dependent) and was first proposed as a tool of the functional study of the brain by Ogawa et. al.[18] There exists a vast literature discussing the theoretical and practical complexity of the fMRI techniques that reaches far beyond what was presented here.[19] With the presented amount of detail at hand, however, it becomes possible to sketch an interpretative scheme operative in the fMRI studies of the cognitive functions of the brain:

> Neuronal activity (NA) → Hemoglobin (Hb) → water ($^1$H-NMR) → Resonance Imaging (IM) → Brain's Image on the screen (BE).

There are many other experimental techniques in biology and medicine that involve the interpretative path of such complexity and there are well

[17] S. A. Huettel, A. W. Song, G. McCarthy, *Functional magnetic resonance imaging*, Sunderland, MA 2009.

[18] S. Ogawa, T. M. Lee, A. K. Kay, D. W. Tank, *Brain magnetic resonance imaging with contrast dependent on blood oxygenation*, "Proceedings of the National Academy of Sciences (USA)" 1990 no. 87, p. 9868–9872.

[19] Cf. W. Bechtel, *Aligning multiple research techniques in cognitive neuroscience: why is important?*, „Philosophy of Science" 69 (2002) no. S3, p. S48–S58.

documented grounds to suppose that fMRI yields the desired information on the neuronal activity under study. What needs to be pointed out, however, is the resulting combination of the different levels of molecular and biological structures that is involved in the ultimate assignment of the observed data on the fMRI's screen to the neuronal activity. What one actually sees on the screen is the spatial distribution of hydrogen atoms of the water molecules that respond to the change of the local magnetic field in their vicinity that affects the magnetic properties of the nuclei. More precisely, these are their states represented by a spin that directly participate in the exchange of energy with the incoming magnetic pulse. These states, in turn, are affected by the spin of the hemoglobin molecule dependent on the presence of the oxygen atom.

## A methodological summary

Two methodological issues need to be addressed at this point. First, all physical magnetic resonance effects refer to the states of the corresponding molecules. It means that as soon as one leaves the domain of physical explanation and switches to the area of biology (as is the case of the blood flow and ultimately the neuronal activity), the explanation regards the interaction of objects such as hemoglobin, blood cells and finally the brain tissue. What remains a question, however, is how the quantum mechanical discourse regarding the spin states of the resonating nuclei is made consistent with the object oriented language of a biological description of the blood flow and the neuronal activity in the end. Secondly, the reason of this state of affairs most likely lies in the fact that, although the physical and biological descriptions are conceptually inconsistent, there exists a deeper unity between microscopic and macroscopic levels. In other words, there are yet unknown laws of nature that show the macroscopic level to be *emergent* from the microscopic one. Roger Penrose is the foremost proponent of such a stance.[20] Possibly, the reason for the present conceptual disunity in the discourse of the cognitive sciences is caused by the limited and fragmentary access of our scientific language into the workings of the nature. This does not imply, however, that unity does not reign at the most fundamental level of the physical reality.

[20] R. Penrose, *The large, the small and the human mind*, Cambridge, MA 1997, p. 84.

## Abstract

The contemporary research in neurobiology heavily rests on the application of complex experimental techniques. The primary aim is to determine the neuronal correlates of various mental phenomena such as abstract thinking, consciousness, free will etc. The application of the contemporary research in neurobiology to understand the nature and the function of the brain is currently having a strong impact on the classical philosophical discourse carried out in area of the philosophy of mind. In this article, a short analysis of one of the most widely used techniques in the neurobiological research is presented, namely, the functional magnetic resonance imaging (fMRI). The particular emphasis is to point out to the conceptual difficulties that arise between the language used at the experimental level (spins, molecules) and how this language might acquire its meaning to eventually refer to the mental phenomena represented by appropriate neuronal structures revealed in the experiment. The apparent disunity will be most likely remedied as a more unified theory relating mental phenomena to the specificity of the most fundamental level of the physical reality becomes available.

## Bibliography

Bechtel W., *Aligning multiple research techniques in cognitive neuroscience: why is important?*, "Philosophy of Science" 69 (2002) no. S3, p. S48–S58.

Brożek B., *Philosophy in neuroscience*, [in:] *Philosophy in science. Methods and applications*, ed. B. Brożek, J. Mączka, W. P. Grygiel, Kraków 2011, p. 163–182.

Butterfield J., Isham C., *Spacetime and the philosophical challenge of quantum gravity*, [in:] *Physics meets philosophy at the planck scale*, ed. C. Callender, N. Huggett, Cambridge, MA 2001, p. 33–89.

Chalmers D., *What is a neural correlate of consciousness?*, [in:] *Neural correlates of consciousness. Empirical and conceptual questions*, ed. T. Metzinger, Cambridge, MA 2000, p. 17–39.

Churchland P. S., *Brain-wise. Studies in neurophilosophy*, Cambridge, MA 2002.

Cosmides L., Tooby J., *Beyond intuition and instinct blindness. Toward an evolutionarily rigorous cognitive science*, "Cognition" 1994 no. 50, p. 41–77.

Damasio A., *Descartes' error. Emotion, reason, and the human brain*, New York 1994.

Davies B., *Some recent articles about platonism*, "EMS Newsletter" 2009 no. 64, p. 24–27.

Grygiel W. P., *Metodologiczne aspekty uprawiania filozofii umysłu w kontekście nauk kognitywnych*, [in:] *Oblicza racjonalności. Wokół myśli Michała Hellera*, red. B. Brożek, J. Mączka, W. P. Grygiel, M. L. Hohol, Kraków 2011, p. 51–62.

*Handbook of functional neuroimaging of cognition*, ed. R. Cabeza, A. Kingstones, Cambridge, MA 2006.

Heller M., *How is philosophy in science possibile?*, [in:] *Philosophy in science. Methods and applications*, ed. B. Brożek, J. Mączka, W. P. Grygiel, Kraków 2011, p. 13–24.

Huettel S. A., Song A. W., McCarthy G., *Functional magnetic resonance imaging*, Sunderland, MA 2009.

Keeler J., *Understanding NMR spectroscopy,* Chichester 2005.

Kurek Ł., *Neurofilozofia jako filozofia w kontekście nauki*, [in:] *Oblicza racjonalności. Wokół myśli Michała Hellera*, red. B. Brożek, J. Mączka, W. P. Grygiel, M. L. Hohol, Kraków 2011, p. 63–82.

Maurer A. A., *Medieval philosophy*, Toronto 1982.

Mumford D., *Why I am a platonist*, "EMS Newsletter" 2008 no. 70, p. 27–30.

Ogawa S., Lee T. M., Kay A. K., Tank D. W., *Brain magnetic resonance imaging with contrast dependent on blood oxygenation*, "Proceedings of the National Academy of Sciences (USA)" 1990 no. 87, p. 9868–9872.

Penrose R., *The large, the small and the human mind*, Cambridge, MA 1997.

Penrose R., *The road to reality*, New York 2005.

Quine W.V.O., *On what there is*, ”Review of Metaphysics” 1948 vol. 2, no. 5, pp. 21–38.

*The MIT encyclopedia of the cognitive sciences*, ed. R. A. Wilson, F. C. Keil, Cambridge, MA 1999.

Wigner E. P., *The unreasonable effectiveness of mathematics in the natural sciences*, "Communications on Pure and Applied Mathematics" 1960 no. 13, p. 1–14.

Załuski W., *Pojęcie osoby w świetle nauk biologicznych*, [in:] *Oblicza racjonalności. Wokół myśli Michała Hellera*, red. B. Brożek, J. Mączka, W. P. Grygiel, M. L. Hohol, Kraków 2011, p. 83–98.