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OPERATIONAL CONCEPTS IN THE HISTORY OF EMBRYOLOGY: METHODOLOGICAL STUDY

Introduction

Operational concepts in the methodology of science are all those whose definition requires referring to a certain sequence of activities (operation). An operational concept is, for example, the concept of a decidable sentence by means of a certain set of empirical procedures. An empirical procedure (which is also an operational concept) can be defined as a sequence of operations performed according to a certain established research program[1].

In the history of embryology, various concepts of this type have been used and have been introduced into the contexts of various theories. They have tried to capture normatively, describe, and inspire biological research on the specifics of embryogenesis and organic development. These include the *vegetative soul* of Aristotle, the *vis essentialis* of Caspar Friedrich Wolff, and the *entelechy* of Hans Driesch.

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1. C. G. Hempel, *Philosophy of Natural Science*, New Jersey 1966, pp. 88-91.

The main task of this work is to characterize the role of selected categories in scientific research, which I call "operational concepts." I don't analyse entire systems or theories in which these concepts played a fundamental explanatory or inspirational role. I also omit the philosophical aspects of the epistemological dispute regarding the concept derivation methods. Such a research approach requires a thorough, individual methodological study.

Teleological and physical operational concepts that inspired research and scientific discoveries

In the case of the above-mentioned scholars, one can speak about the characteristic of the operational concepts to inspire investigation in the course of embryological research. It is mainly about planning and preparing biological observations and experiments as well as making comparisons and theoretical generalizations in discovering epigenetic specificities.

The specificity of embryological investigations was often limited to the question of formative cause, that is, what forming processes led to the formation of a given organ or function in the course of ontogenesis. Also considered was the purpose an organ brought to an individual as a representative of a particular species. In this regard, it was asked "why," for example, the butterfly needed such and such a form and colour for its wings. In the second case, one enters upon the area of teleological explanatory concepts, which are avoided in physics and chemistry[2].

Throughout the history of science, research has been carried out from different methodological perspectives. As a result, operational concepts were of different nature and had different methodological assumptions. When conducted on the foundation of the legitimacy of mechanistic theories, they were often purely physical concepts (functional). When taking the perspective of vitalist assumptions, they often had a teleological character. Operational categories also took the form of metaphysical concepts. The legacy of the philosophy of nature shows that concepts of a physical nature were justified within the framework of mechanistic theories. All of them resulted in the discovery of certain new classes of organic phenomena and specificities and contributed to changes in observational and experimental practices in embryological research[3].

2. Z. Kochański, *Problem celowości we współczesnej biologii*, Warszawa 1966, p. 123.
3. See J. Needham, *Chemical embryology*, London 1931, pp. 41-220.

Aristotle's vegetative soul (ψυχή) as an operational concept of a teleological character

In Aristotle's methodology, the vegetative soul was a specific cause and an integral component of his scientific theory. It was introduced to his purposeful description of the development of the dynamics of the living world. It fulfilled the criteria of operability related to explaining the wholeness of intrinsically complex epigenetic development and regeneration processes:

> For nature, like intelligence, acts for a purpose, and this purpose is for it an end. Such an end the soul is in animals, and this in the order of nature, for all the natural bodies are instruments of soul: and this is as true of the bodies of plants as of those of animals, shewing that all are means to the soul as end; where end has two senses, the purpose for which and the person for whom. Moreover, the soul is also the origin of motion from place to place, but not all living things have this power of locomotion. Qualitative change, also, and growth are due to soul. For sensation is supposed to be a sort of qualitative change, and nothing devoid of soul has sensation. The same holds of growth and decay. For nothing undergoes natural decay or growth except it be nourished, and nothing is nourished unless it shares in life[4].

On the one hand, the operational concept of Aristotle's substantial type was derived from observation; on the other hand, it inspired his further research methodology, useful in perceiving the specificity of epigenetic development (quantitative and qualitative changes in the developing organism). The Stagirite clearly saw the difference between the change from one form of composition to another and epigenesis, in which composite organs did not arise from one another, but one after the other[5].

About this great scholar, Joseph Needham wrote:

> If I have devoted such ample space to an account of Aristotle's contributions to embryology, it is, firstly, because they are actually greater in number than those of any other individual embryologist, and secondly, because they had so profound an influence upon the following twenty centuries. Embryology from the third century B.C. to the seventeenth century A.D. is meaningless unless it is studied in the light of Aristotle[6].

For almost two thousand years, no one had put forward any theory that could seriously compete with the Aristotelian conception of biological life. The most

4. Aristotle, *De Anima*, II, 415b3-416a6, cited from: Aristotle. (1907). De Anima. Ed. by Robert Drew Hicks. Cambridge: Cambridge University Press.
5. Aristotle, *De Partibus Animalium* I and De *Generatione Animalium* I, (II, 1, 734). Translated by D. M. Balme, New York 1972.
6. J. Needham, *A history of embryology*, New York 1959, p. 54.

prominent and influential representatives of the biological thought of Antiquity and the Middle Ages confirmed the correctness of the philosopher's empirical generalizations with their observations and recognized the legitimacy of the vegetative soul postulate – as an operational concept.

The time finally came when the organism was considered as a ready-made machinery of prefabricated parts, and epigenetic development remained known only to the few who could resist the fashionable blindness of the Enlightened Age. The history of embryology calls this period the reign of preformation theory[7].

Vis essentialis of C. F. Wolff as a physical operational concept: A great return to the theory of epigenesis

Vis essentialis, postulated by Wolff as an operational concept, was instrumental in planning embryological observations and the method of explaining the perceived specific epigenetic processes, that is, i.e. the movement of organic fluids in the body and the formation of parts (from scratch) in specific places:

> Be this force as may, whether attractive or repulsive, or dependent on the expansion of air or composed of all these, and some more, provided it produces the aforementioned effects [the absorption and diffusion of liquids through the whole plant, and their exhalation] and provided it is supposed along with the plant and the nutritive humors received – which experience confirms – it will suffice for my present purpose and I shall call it vis essentialis of the vegetals"[8].

In a broader sense, this concept, as a component of Wolff's scientific theory, contributed to the overthrow of the preformation theory, dominant at the time. Despite the fact that Wolff strongly opposed the mechanistic theory (mechanistic medicine), he defined his operational concept *vis essentialis* in the aspect of specifically mechanistic. His great achievement is the confirmation of the epigenetic theory on an observational foundation. The attribution of physical properties to *vis essentialis* could have been caused by the great influence of classical physics as well as by the mainstream preformationist explanation.

7. P. Lenartowicz, *Elementy filozofii zjawiska biologicznego*, Kraków 1984, p. 168.
8. C. F. Wolff, *Theoria generationis*, Halae ad Salam 1759, § 4, p. 13.

Entelechy (εντελέχεια)[9] of Hans Driesch as an operational concept: The clash of statical teleology with dynamical teleology

Driesch in his experimental research (treated as a starting point) was concerned with the factor E as an operational concept understood in a specific physical way in relation to organic phenomena. As in physics and chemistry, force, energy, mass, and the like are not some metaphysical "entities" in relation to specific physical and chemical objects and phenomena, but are their objective and universal natural parameters, strictly measurable and fully predictable in their specific values. At this point, in a general way, we can compare Driesch's operational concept with Wolff's *vis essentialis* regarding the physical character of the two categories.

Driesch, in the course of his research, still on a reductionist foundation, was looking for a universal natural parameter E, which I call the operational concept. In this regard, he wrote:

> For practical purposes it seems better if we modify the statement of our question. Let us put it thus: E is one of the factors responsible, among variables, for the localisation of organic differentiation; what then do we actually know about the causal factors which play a localising part in organogenesis? We, of course, have to look back to our well-studied "formative stimuli." These stimuli, be they "external" or "internal", come from without with respect to the elementary organ in which any sort of differentiation, and therefore of localisation, occurs: but in our harmonious systems no localising stimulus comes from without, as was the case, for instance, in the formation of the lens of the eye in response to the optical vesicle touching the skin. We know absolutely that it is so, not to speak of the self-evident fact that the general "means" of organogenesis have no localising value at all[10].

The quoted fragment proves that Driesch initially intended to assign physical properties to the E category under consideration. This attempt was doomed to failure. The scholar was unable to specify a constant value that would meet the expected morphogenetic properties. This type of methodology reveals the scientist's path leading to metaphysics and contributes to the shaping of an operational concept with a clear teleological character.

9. It should be noted that H. Driesch took the term entelechy from Aristotle. However, he gave it a different operational meaning: "The great father of systematic philosophy, Aristotle, as many of you will know, is also to be regarded as the founder of theoretical biology. Moreover, he is the first vitalist in history, for his theoretical biology is throughout vitalism; and a very conscious vitalism indeed, for it grew up in permanent opposition to the dogmatic mechanism maintained by the school of Democritus". See, H. Driesch, *The Science and Philosophy of the Organism*, Aberdeen 1908, vol I, pp. 143-144.
10. H. Driesch, *The Science and Philosophy of the Organism*, Aberdeen 1908, vol I, pp. 132-133.

> What then is our elemental vital factor in nature? Let us only say in this place that entelechies remain "elemental" also with regard to their true ontological character, just as they were elemental with regard to the law they obey. Entelechies are *not* energies, *not* forces, *not* intensities, and *not* constants, but entelechies. Entelechy, as we know, is a factor in nature which acts teleologically. It is an intensive manifoldness, and on account of its inherent diversities it is able to augment the amount of diversity in the inorganic world as far as distribution is concerned. It acts by suspending and setting free reactions based upon potential differences regulatively. There is nothing like it in inorganic nature[11].

Both passages of text clearly show that Driesch's fundamental operational concept has evolved. In the first phase of his research, it had physical properties, then it took the form of a teleological category of a metaphysical nature. While Driesch did not succeed in working out any universal constant rule of development, the above operational concept inspired his research and led to the discovery of a deeper foundation in the field of organic regeneration. In this respect, Driesch established other important concepts on the embryological level, such as *prospective power* and *prospective meaning*. Both were confirmed and explained by H. Spemann and H. Mangold[12].

Conclusions

Operational concepts were the starting point and initially defined the causal aspect of the development of embryological specifics. Therefore, they became the basis for the specifying of operational definitions used to describe and explain natural reality. They allowed for the definition of properties, relations, states of affairs, and observational-experimental situations. In turn, the set of laws and principles developed gradually within a given methodology. The concepts appearing in them are related in various ways to each other and with pre-theoretical concepts. These relationships are often the bases of new operational application criteria.

The history of the methodology of biology shows that operational concepts were specified in various ways, that is, both based on the inductive and deductive

11. H. Driesch, *The Science and Philosophy of the Organism*, Aberdeen 1908, vol I, p. 205.
12. I consciously refrain from discussing H. Spemann's concept of the "organizer". I only point out that, in general, his concept can be compared with Driesch's factor E in the physical dimension. See H. Spemann, H. Mangold, *Über Induktion von embryonal Anlagen durch Implantation arframderorganisatoren*, "Archive für Entwicklungsmechanik der Organismen", 1924, v. C, pp. 599-638; D. A. Szkutnik, *Methodological Foundation of the "Organizer" on the Field of Embryological Phenomena according to Hans Spemann*, "Archives of The History and Philosophy of Medicine", 2017, v. 80, pp. 30-37.

method. Cognitive methods were often intertwined and thus complemented each other[13]. In this respect, the dispute over the validity of the method of knowledge – as Feyeraband aptly points out – is unjustified[14].

Often, attempts to “transform” operational concepts into specific principles or morphogenetic rules have been unsuccessful. However, they have resulted in the discovery of deeper developmental foundations in the field of morphogenesis. It can be said that in this respect they were cognitively fruitful. In the case of Aristotle, Wolff, and Driesch, these were (generally speaking) pertinent arguments in favour of the epigenetic concept. Within this framework, they made a series of discoveries that are often forgotten. As a reminder, we will mention the most important of them.

The most important discoveries of Aristotle in the field of embryology alone:

1. He introduced the comparative method into embryology and, by studying a multitude of living forms, was able to lay the foundation for the future science of the various ways in which embryonic growth can take place. Thus he knew of oviparity, ovoviviparity, and viviparity, and one of his distinctions is substantially the same as that known to modem embryology between holoblastic and meroblastic yolks.
2. He distinguished between primary and secondary sexual characteristics.
3. He pushed back the origin of sex-determination to the very beginning of embryonic development.
4. He associated the phenomena of regeneration with the embryonic state.
5. He realized that previous speculations on the formation of the embryo could be organized into the definite antitheses of preformation and epigenesis, and he decided that the latter alternative was the true one.
6. He put forward a conception of the unfertilized egg as a complicated machine, the wheels of which would move and perform their appointed function in due course when once the master-lever had been released.
7. He foreshadowed the theory of recapitulation in his speculations on the order in which the souls came to inhabit the embryo during its growth, and in his observation that universal characteristics precede particular characteristics in embryogeny.
8. He foreshadowed axial gradient theory by his observations on the greater and more rapid development of the cephalic end in the embryo.

13. I am not assessing here the adequacy of inductive or deductive reasoning in biological cognition. I only indicate that particular methods played an important role in the natural research of Aristotle, Wolff, and Driesch.
14. P. Feyerabend, *Against Method: Outline of an Anarchistic Theory of Knowledge*, London 1975.

9. He allotted the correct functions to the placenta and the umbilical cord.
10. He gave a description of embryonic development involving comparison with the action of rennet and yeast, thus foreshadowing our knowledge of organic catalysts in embryogeny[15].

Wolff's most important discoveries in the field of embryology:

1. He rejected the preformation theory.
2. Methodologically and experimentally, he (again) established the theory of epigenesis.
3. Wolff's research carried out on chickens led him to conclude that the intestines, skin, and all other organs of the embryo tend to develop in a specific way. He laid the foundation for the germ layer theory. Wolff foreshadowed the germ layer theory by showing that the material out of which the embryo is constructed is, in an early stage of development, arranged in the form of leaf-like layers. His theory was then developed by Pander and von Baer.
4. He was the discoverer of primitive kidneys (mesonephros), or "Wolffian bodies," and their excretory ducts.
5. In 1768-1769, he published his best work in embryology on the development of the intestine[16].

The most important discoveries of Driesch in the field of embryology:

1. Experiments and observations of the phenomena of regulation led him to specify such concepts as *prospective power* and *prospective meaning* as expressions of a certain possibility of the actual development of the embryo.
2. The description of the embryo as a certain system he introduced was then—together with a physical and theoretical vision of the whole consisting of parts—made the direct starting point for the later development of cybernetics.
3. He laid the foundation for biological research conducted today in the fields of totipotency and regenerative medicine.
4. He confirmed with even greater clarity the validity of the comparative method in embryology.

One of the most important problems in the methodological development of individual operational concepts is the distortion of their original meanings. Related to this is a misunderstanding of entire theories or explanatory systems[17]. In the

15. See, J. Needham, *A history of embryology*, New York 1959, pp. 54-56.
16. C. F. Wolff, *De formatione intestinorum*, Sankt Petersburg 1769.
17. I am just pointing out this issue without discussing it in detail.

case of the researchers discussed here, such a misunderstanding is, for example, the conceptual assignment of static properties to concepts of a clearly dynamic nature. In this respect, it is also the "mixing" of static teleology with dynamic teleology (e.g. in Aristotle and Driesch).

In the methodology of science, there is also a tendency to replace teleological language with functional (physical) language. Is a functional, physical language able to adequately describe the dynamic course of morphogenetic development? To this day, however, disputes continue in this area.

The history of science shows that the operational concepts to which their creators assigned specific content inspired research and great scientific discoveries in the field of morphogenesis. They can still inspire certain research activities when considered in accordance with their starting assumptions and established research criteria, adopted within the framework of the broadly understood methodology of science.

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Summary

The aim of the present work is to discuss select concepts called by me "operational concepts." Despite the fact that they were introduced to biological research from different epistemological perspectives, they have all played an important role in the development of embryology as a science. They have been useful cognitively in planning observations and biological experiments in the area of morphogenesis. They have constituted an essential causal element of theories explaining and describing the course of epigenetic processes.

Key words: operational concepts, Aristotle, C. F. Wolff, H. E. Driesch, teleology, reductionism, epigenesis, vegetative soul, vis essentialis, entelechy.

POJĘCIA OPERACYJNE W HISTORII EMBRIOLOGII: STUDIUM METODOLOGICZNE

Streszczenie

Przedmiotem niniejszego opracowania jest omówienie wybranych pojęć nazywanych przeze mnie „pojęciami operacyjnymi". Pomimo tego, że zostały wprowadzone do badań biologicznych z różnych perspektyw epistemologicznych, wszystkie odegrały ważną rolę w rozwoju embriologii jako nauki. Były przydatne poznawczo w planowaniu obserwacji i eksperymentów biologicznych na obszarze morfogenezy. Stanowiły istotny element przyczynowy teorii wyjaśniających i opisujących przebieg procesów epigenetycznych.

Słowa kluczowe: pojęcia operacyjne, Arystoteles, C. F. Wolff, H. E. Driesch, teleologia, redukcjonizm, epigeneza, dusza wegetatywna, vis essentialis, entelechia.