

The impact of the Zoological Station in Naples on developmental physiology

IRMGARD MÜLLER*

Faculty of Medicine, University of Bochum, Bochum, Germany

Foundation and special status of the Zoological Station

The history of the Zoological Station in Naples and the biography of its founder Anton Dohrn (1840-1909) has been described in detail on several occasions (Heuss, 1962; Kühn, 1950; Müller, 1975a, 1976; Partsch, 1980); it suffices therefore to introduce only the essential elements of this early model of international collaboration in the natural sciences.

Anton Dohrn, the founder of the first marine biological research institute studied medicine and zoology in Königsberg, Bonn, Berlin, Breslau and obtained his "habilitation" (*venia legendi*) in Jena 1868. Motivated by his long-time friend and teacher Ernst Haeckel (1834-1919), Dohrn initially worked on phylogenetic problems and published numerous papers on the genealogy of arthropods and vertebrates in which he organized individual phyla into evolutionary trees which were at once daring and original (Müller, 1994). As fervent admirer and defender of Darwin and his theory of descent (Groeben, 1982), he made the elucidation of phylogenetic relationships among animals not only the goal of his morphological systematic studies, but also the central objective of his organizational efforts. With private funds and personal initiative, in 1872-1873 he created an international research institute in Naples on the coast of the Mediterranean Sea, which was extremely rich in species diversity. He initially maintained the institute with his personal inherited funds in order to fend off political interests. He came up with a number of innovative measures to finance his unique enterprise that contributed to cover expenses on the one hand, but fostered on the other hand interdisciplinary cooperation and assured the Institute's international status. They included the introduction of the so-called "bench system" (rental of work space or research units to national and foreign scientific institutions on an annual basis),

sale of preserved animal specimens, and the foundation of three serial publications (*Mitteilungen aus der Zoologischen Station Neapel/Pubblicazioni della Stazione Zoologica di Napoli; Zoologische Jahresberichte; Fauna und Flora des Golfes von Neapel*) and the establishment of a public aquarium. Dohrn, consumed by his scientific mission, indeed succeeded in gaining the material and intellectual support from the heads of all important European states, which made it possible to realize his projects for decades. The special status, which Dohrn provided in this manner for the Zoological Station, among other scientific institutions of the 19th century, and explained its high efficiency during the founding years, was based on the fact that it was both an international organization in its scientific participants and funding, as well as typically German with regard to its structure and conception. By location, it was considered an Italian institute. In reality, however, it was the private property of a single researcher (Müller, 1976).

Dohrn deliberately avoided putting this labile system of interests on solid legal ground. While rejecting definitive financial security, with his diplomacy and skilful dealing with national vanities, Dohrn protected his institute from the danger of bureaucracy and paralysis of government administration. This unbureaucratic character assured the station its swift adaptability to new needs, its scientific mobility and receptiveness for new ideas and directions. However, such an administration was sensitive to disturbances from within and without, and was not suited to continue beyond Anton Dohrn's death and World War I. Yet the struggle regarding international status, property rights and leadership that has been going on to this time (Partsch, 1980) shall not be considered here any further.

Abbreviations used in this paper: AZSN, Archives of the Zoological Station, Naples.

*Address for reprints: Faculty of Medicine, Ruhr University of Bochum, Malakowturm, Markstraße 258a, D-44799 Bochum, Germany. FAX: 234.7094205.



Fig. 1. Advertising placard for the Naples Zoological Station painted by Comingio Mercuriano (1845-1915), artist at the Zoological Station, 1902.

The Zoological Station as the germ cell of developmental physiology

Although Dohrn himself dealt with developmental history from a purely descriptive angle and he did not see a necessity to depart from the exclusively morphological perspective, the Neapolitan Station nevertheless evolved during his lifetime into a center of experimental embryological research that was unique at the time. The initial impetus and point of departure of developmental physiological research were the investigations of Theodor Boveri's (1862-1915) who followed initial suggestions for developmental physiological research on sea urchins from Richard Hertwig (1850-1937) in München (Baltzer, 1962, 1963; Röntgen, 1918; Cremer, 1985).

Theodor Boveri, who first came to the Zoological Station in 1887-88 has visited Naples many times until 1914, one year before his death; altogether twenty publications came out of Boveri's Neapolitan studies. Along with Boveri there came a new research method to Naples which became widely accepted among zoologists, following the famous discovery by Oskar Hertwig (1849-1922). It related to an observation of Hertwig, who had detected in 1875 the entry of a sperm into the sea urchin egg and recognized the fusion of the egg and

sperm nuclei as the essential event of fertilization (Hertwig, 1875).

Hertwig's discovery stimulated researchers to investigate the internal and external developmental factors by doing experiments with artificially caused developmental defects. Thus, the sea urchin egg, which is very resilient, easy to obtain, easy to culture, and fully transparent, with Hertwig's discovery became the favored research material in experimental cell studies. Once again, a frequently observed fact in biology repeated itself: discovery of a suitable research object opens up a wide new field of studies.

Boveri demonstrated in his first series of sea urchin experiments (Boveri, 1889) that egg fragments without an egg nucleus — he called them merogones — after fertilization could continue their development into normal larvae. In doing so he proved on the one hand that the egg nucleus is dispensable for the process of fertilization. On the other hand, he demonstrated that the paternal chromosomes, together with egg cytoplasm could suffice for normal (in this instance paternal-haploid) development to occur. To establish whether protoplasm, the nucleus, or both determine inheritance, Boveri began in Naples in 1889 his famous experiments with "hybrid merogones" which concerned him to the end of his life and which attracted a growing number

of researchers to Naples because of its immense theoretical significance (Müller, 1975b, 1976).

With the goal in mind to test the contribution of the nucleus to the heritable material, Boveri fertilized enucleated egg fragments of one sea urchin species (*Sphaerechinus*) with sperm from a different species (*Echinus*) and attempted to culture the resulting larvae. As a result of his hybridization experiments, he obtained larvae which revealed exclusively characteristics of the paternal species, whereas intact eggs or egg fragments containing the egg nucleus always produced larvae which represented an intermediary form between the parental species with regard to their morphology and skeletal structure. Boveri concluded that only the nucleus could propagate heritable factors while the maternal protoplasm had no influence on the form of the new organism. (Boveri, 1890). For Boveri, this experiment seemed to prove the dominant role of the nucleus. However, later Boveri had to acknowledge that his experiments contained technical errors that were explained only sixty years later by Leopold von Ubisch (1886-1965) (Ubisch 1954/1957), also at the Zoological Station, utilizing the glass needle method (Spemann, 1923) that was introduced by Hans Spemann (1869-1941).

Boveri's most important contribution was without any doubt the proof in 1902 that chromosomes are qualitatively different from one another. It resulted from his classical di-spermy experiment, also performed in Naples in which he investigated sea urchin eggs that were fertilized by two sperm cells (Boveri, 1903). In doing so, Boveri followed up an observation by Hans Driesch (1867-1941), whom he met several times in Naples. Driesch had already described in 1893 that, following entry of two sperms into one egg, (i.e., double fertilization), a tetrapolar spindle would be formed, but he provided no detailed explanation of this phenomenon (Driesch, 1893). Boveri, utilizing Driesch's method, noticed that isolated blastomeres reared from double fertilized eggs developed pathologically. Boveri traced the variable and abnormal development of these embryos back to an irregular distribution of the chromosomes at the tetrapolar spindle. He came to the conclusion that not a certain number, but a certain combination of chromosomes was required for normal development. This finding, however, implicated that individual chromosomes are unequal and must possess different qualities.

With this experiment, Boveri had not only provided a strong proof for the significance of chromosomes in the developmental processes of organisms, but also a convincing argument for the genetic inequality of individual chromosomes. Therefore, Boveri in 1903 was the first to point out the agreement of his cytological discoveries with the results of Mendel; he even predicted new phenomena like gene coupling and exchange among parts of chromosomes. Thus, Boveri was one of the first to provide with his chromosome theory of inheritance, a key to the understanding of the then just-rediscovered rules of Mendel.

Based on the double fertilization experiments, Boveri also proposed already in 1903 the suggestion of a possible connection between tumor formation and multipolar mitoses because of abnormal chromosome combinations. Boveri's discussion of multipolar mitoses in 1903 closed with the statement "That multipolar mitoses under certain circumstances lead to tumor-like structures. ... However, if I review what has been learned from the etiology of carcinoma, regarding the many physical and



Fig. 2. Anton Dohrn (1840-1909). Photograph about 1900.

chemical insults, and then observe on the other hand that mainly pressure, shaking, narcotics, abnormal temperature are the agents that allow us to generate multipolar mitoses in young embryos, then it seems to me possible that we have in front of us in these observed instances the complete causal chain of certain tumors" (Boveri, 1903). Boveri pursued this problem later on without arriving at a clear cut result, as can be seen from a letter to Anton Dohrn: "I have struggled since my winter stay in Naples with experiments to produce multipolar mitoses in mammals, because I had hoped to obtain certain information about the tumor problem. For a long time the whole thing did not work, and only now, as I have become aware of a new method is there some hope for success." (T. Boveri to A. Dohrn 8.5.1907, AZSN, A 1907).

For his further experiments, Boveri benefited from a chance discovery of the zoologist Kurt Herbst (1866-1946) whom Boveri met on several occasions in Naples (Müller, 1976, 347f). Herbst had observed in 1900 that cells in cleavage embryos spontaneously separated from each other in calcium-free sea water (Herbst, 1900). In this way, an elegant and gentle method became available to isolate any one blastomere undamaged and to follow its further development.

Boveri also managed to utilize a remarkable discovery of the American zoologist Thomas Hunt Morgan (1866-1945) to experimentally solve his scientific problems. Morgan worked in Naples around the turn of the century several times before he occupied his place in the annals of research on inheritance as a *Drosophila* researcher and geneticist. Already in 1895, during a research visit to Naples, he noticed that a tri-polar nuclear spin-

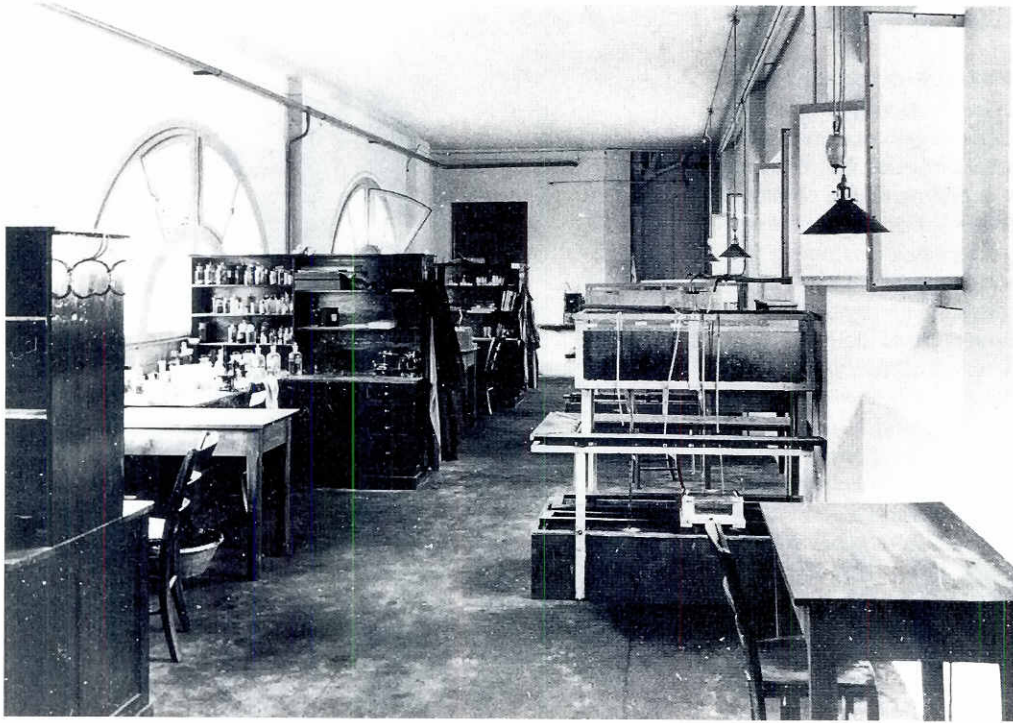


Fig. 3. "Working Table" at the Naples Zoological Station, 1883.

ple would form when eggs were shaken shortly after a di-spermic fertilization. (Morgan, 1896). Boveri utilized this method on several occasions to generate abnormal chromosome combinations in order to experimentally demonstrate his theoretical concepts of qualitatively different chromosomes. In this manner, through international contact with visiting researchers at the Naples station, as stressed an evaluation by the American embryologist Edmund Wilson (1856-1939), Boveri the cell biologist "performed the proper fusion of cytology, embryology, and genetics through the slow and laborious process of observation, experimentation and analysis" (Röntgen, 1918). This achievement is the more remarkable because Boveri arrived only slowly at the discipline of developmental physiology. He began with studies in comparative anatomy, among which his discovery of the nephridia (kidneys) of "*Amphioxus*", (*Branchiostoma* in today's nomenclature) is most remarkable (Boveri, 1891). His theory of chromosome individuality initially was also a purely morphological concept. Consequently, in the beginning his argumentation was strictly based on morphological description. Only after he recognized its limitations in explaining developmental physiological events, did he seek further-reaching experimental methods.

A similar change in methodology was made by the already-mentioned Hans Driesch who started out with morphological investigations of the construction principles of hydroid polyps (Driesch, 1890-1891). Impressed by the program of developmental mechanics which Wilhelm Roux (1850-1924) proclaimed in 1889 as the anatomy of the future in a highly-regarded formal address (Roux, 1889), he very soon turned to experimental investigations on the sea urchin. His choice of sea urchin eggs as study object was guided by the studies of Boveri and the brothers Hertwig. Like Boveri after his first successful experiments, Driesch travelled every winter and spring for a decade to

Naples where he repeated Roux's famous hot needle experiments with sea urchin eggs. As is well known, Driesch made opposite observations (Driesch, 1891/1893): the first two cleavage cells of the sea urchin egg which he separated by egg shaking, did not develop as expected from Roux's results into a half-embryo each. Instead, each developed a complete gastrula and then into a complete, albeit smaller, sea urchin larva. From these results, which contradicted the predetermination of embryonic regions, as postulated by Weismann and Roux (Mocek, 1974), Driesch deduced a holistic capacity of the egg for regulation, which he later developed into the concept of "the harmonious-equipotential system". As for Boveri, the elegant method to gently isolate blastomeres from fertilized sea urchin eggs in calcium-free sea water, developed by Kurt Herbst in Naples, because the necessary prerequisite for the success of his experiment. From his diverse experiments in which he removed and replaced any portion of the embryo, Driesch arrived at the conclusion that the fate of any part of the egg was not determined from the beginning. Instead, the possible fate of an embryonic part, the so-called "prospective potency" was greater than its normal outcome, the "protective fate", such that a fragment of an egg can develop into something else — either more or less — than is normally anticipated. However, upon further experimental analysis of the regulation and regeneration processes, it became quickly apparent that a mechanistic model was unable to explain the complex results. Therefore, Driesch postulated a non-material causal agent that initiates, directs, and controls developmental processes in order to control morphogenesis, or "the transformation of the possibilities into the wholeness of an actuality". These integrated directing, shaping, and developmental forces of the embryo Driesch named "Entelechie" in reference to Aristotle. According to Driesch's personal interpretation, this term expressed that "something is at work that is of non-physi-

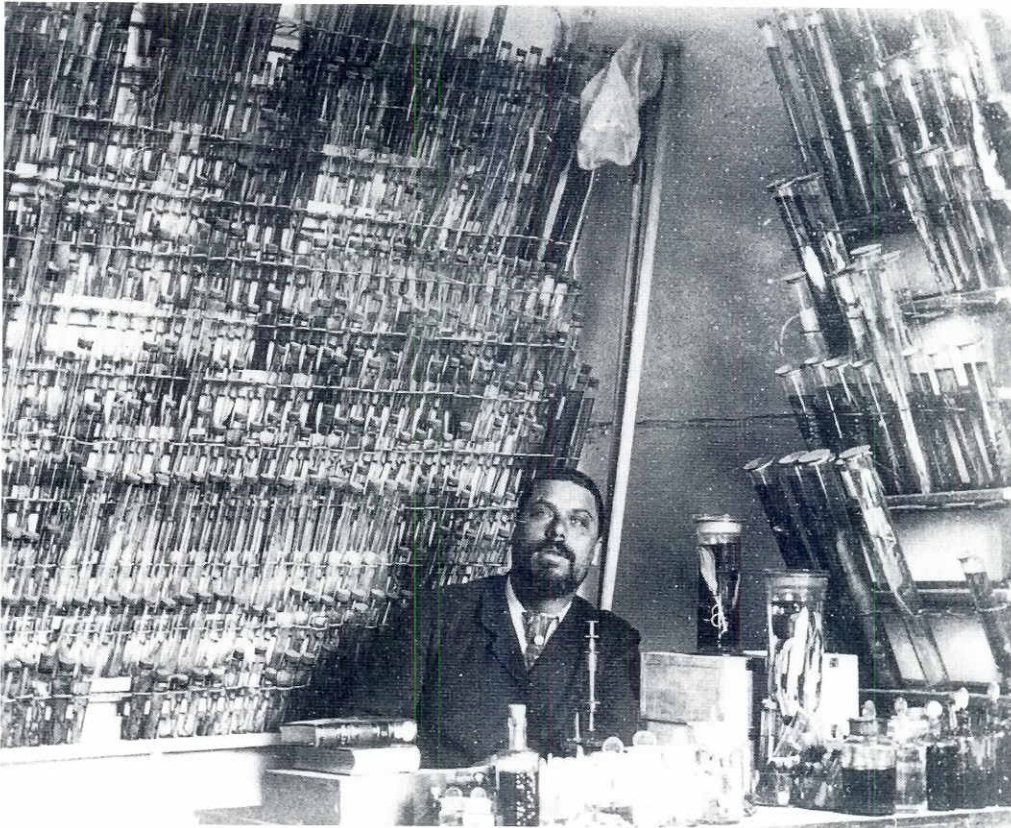


Fig. 4. Salvatore Lobianco (1860-1910), head of the Conservation Department of the Zoological Station.

co-chemical character" and can only be recognized by its effects (Driesch, 1899, 1951).

Later on, Driesch became less interested in the biological understanding of morphogenesis as he focused more and more on the fundamental property of the autonomy of the living state, which finally led him from biology to philosophy (Driesch, 1909). Driesch whose work significantly contributed to the change from descriptive to experimental embryology, later confessed, looking back in his autobiography, that he arrived at his brilliant success to a high degree owing to his numerous stays in Naples where he began his philosophy literally "ab ovo". In a 1911 letter to Reinhard Dohrn (1880-1962) he gratefully acknowledged "my whole scientific personality is rooted in Naples and while biology was a transitory stage . . . it was a transit that indeed determined its direction. This could only be achieved on the basis of your father's great creation" (H. Driesch to Reinhard Dohrn, 29.10.1911, AZSN, A 1911; Driesch, 1951).

Driesch's provocative theses and his contempt for morphology and phylogeny seemed like a radical destruction of the goals pursued by Dohrn and the older generation of morphologists. However, Dohrn did not condemn the renegade developmental mechanic. This is representative of his tolerance, openness, and undogmatic position towards new and well-founded theories, which he accepted, although he himself could not follow the new development. Dohrn's liberal position is evident from an evaluation of Driesch of 1903. Both "Wilson and I are very sympathetic with the young author whose exceptionally rigid and remarkably strong mind has been at work for twelve years to dig a new bed for morphological thought and research. I am completely impar-

tial as I say this, particularly since all of my scientific work has simply been relegated to the level of mere amateurism, which can hardly be taken quite seriously! Of course, I don't think I shall accept the unceremonious decapitation, and someday I shall know how to speak of my own development; but I fully understand what motivates him and I value his position and conclusions, although I cannot follow his arguments all the way" (Heuss, 1962, S.350).

Another example of the group of researchers who were slowly transformed under the influence of the Zoological Station from descriptive morphologists to experimental zoologists, is the American zoologist Edmund Beecher Wilson (1856-1939), who contributed essential building blocks to the chromosome theory of inheritance (Wilson, 1896). Before he came to Naples, Wilson worked at Johns Hopkins University with William Keith Brooks (1848-1908) the staunch Darwin supporter, on problems of evolution, phenomena of adaptation, genealogy, and homology. Consequently, his first visit to the Zoological Station dealt with the solution of a morphological problem, the much-debated formation of the mesoderm in different species (Wilson, 1889). This came at a time when Dohrn's first assistant in Naples, Nicolai Kleinenberg (1842-1897) had just published a much-debated study on the existence or nonexistence of the middle germ layer (Müller, 1973). Based on numerous embryological studies on different *Hydra* species, Kleinenberg had decided to eliminate the "mesoderm stranglehold" as he called it, although the English embryologist Francis Maitland Balfour (1851-1882) had reached, also in Naples, opposite results. Wilson, however, initially wanted nothing else but to scrutinize the explanatory value of the

germ layer theory for the theory of descent. Under the influence of Driesch, Jacques Loeb (1859-1924), and Boveri, Wilson lost his interest in phylogenetic questions and moved over more and more to the field of experimental embryology, which had taken up once again the old debate about preformation and epigenesis.

Wilson expressed an enthusiasm about the works of Roux and Driesch that, in his opinion, initiated a new era in the history of embryology (Wilson, 1893). Thus came about Wilson's classic studies on mosaic cleavage, and his interest in embryology finally led him to cell and chromosome research, which occupied him for the rest of his life. Later he became the leader of the American school of cytology and in the research of inheritance. He participated decisively in the elucidation of the convoluted processes of the maturation divisions in germ cells and independently of N.M. Stevens (1861-1912), he discovered the sex chromosomes in 1905 (Wilson, 1905).

Together with Wilson, the transfer of experimental embryology to America where the zoologists adhered much stronger than their German colleagues to descriptive morphology, was achieved by Jacques Loeb, hardly a less influential visiting researcher of the Zoological Station (Pauly, 1987). Jacques Loeb represented just about the opposite of Hans Driesch. Contrary to Driesch's vitalistic views of the organism, Loeb adhered to a strictly mechanistic position, although — which is remarkable for the history of science — both researchers applied very similar methodology in their sea urchin experiments to prove their theoretical-philosophical positions. Loeb started out as a plant physiologist with Julius Sachs (1832-1897), the founder of the concept of tropisms in Würzburg. Loeb attempted in 1889/90 to reveal in the animal kingdom such tropisms — a term given by Sachs for the stereotype movement of plants that were induced by physical excitations, light, and gravity (Loeb, 1890). His experimental results seemed to confirm his assumption that animals also displayed heliotropism. Consequently, Loeb rejected the widely-accepted anthropocentric view that motility in animals was solely directed by indeterminable impulses like curiosity, feeding drive, instinct, desire, and repulsion. Rather, he believed, based on simple experiments with lower invertebrates, that he had proven that light was the essential factor controlling animal motility. Therefore, Loeb radically and consistently explained animals as photosensitive machines, governed by the laws of light, and he considered the widely-debated colorful concept of animal will power as a reaction of photosensitive substances in the head.

Applying numerous mechanistic and chemical explanatory principles, he tenaciously attempted to widen this concept beyond its narrow limits of justification into a comprehensive theory of animal reactivity based on physico-chemical constants. Therefore, in Naples, Loeb concerned himself with phenomena of regeneration that seemed to confirm his materialistic-mechanical position. In numerous experiments he studied the conditions of the formation of new organs and the possibilities of controlling and regulating morphogenesis by external influences. He amputated, fragmented, and generated any possible defect and deformation. Out of a piece of the trunk of the hydrozoan *Tubularia mesembryanthemum* he created hydroids instead of rhizoids. From isolated fragments of planaria he produced two headed planaria and on numerous organisms he created at will a bi-basal or bi-oral reorganization (Loeb, 1891/92). Above all, Loeb

concentrated on the question of how an organism prevents regeneration in those untreated parts which are induced to renewed growth after amputation. Loeb explained growth and regeneration with the accumulation in certain cells and regions of morphogenetic specific or unspecific substances that circulate throughout the organism. According to Loeb's view, these growth factors accumulated after the isolation of portions from the whole, because of an interruption of the normal material transport or circulation. He specifically stressed the holistic view of the organism: "The action of the organism as a whole seems nowhere more pronounced than in the phenomena of regeneration, for it is the organism as a whole which represses the phenomena of regeneration in its parts, and it is the isolation of the part from the influence of the whole which sets in action the process of regeneration" (Loeb, 1916, p. 153). Loeb was firmly convinced, that the obscure regeneration processes could be reduced to physico-chemical reactions: "It must be said, however, that any theory of life phenomena must be based on our knowledge of the physico-chemical constitution of living matter and neither Darwin nor Lamarck was concerned with this" (Loeb, 1916, p.6). Although these growth-promoting substances were only indirectly demonstrated, in Loeb's opinion they made unnecessary the assumption of hypothetical holistic and goal-oriented forces on which, for example, Driesch based his concept of Entelechie. He thus principally excluded vague morphogenetic forces.

The resonance of these spectacular experiments, together with the basic concept of organisms as chemical machines, was overwhelming, especially among the younger generation of zoologists. Many years later, the zoologist Kurt Herbst, who personally experienced the impact of Loeb's experiments in Naples, remembered the excitement they generated among the zoologists. According to his eye-witness report, these experiments had the effect of a "bright ray of sunlight which suddenly fell on the darkness of morphology, which at that time was fully captivated by phylogenetic research . . . The impact of these publications was so great that they can only be compared to that of the works of Trembley, Bonnet and Spallanzani, on researchers and lay people alike in the second half of the eighteenth century; because, just like the onset of a flood of research on regeneration phenomena at that time, now a second tidal wave rolled in following the appearance of Loeb's contributions, leading to a fertile and rich harvest for the biological sciences" (Herbst, 1924).

Loeb's sensational results, which raised the expectation that animal morphogenesis could be controlled like a machine, initiated a flood of new studies on problems of regulation and regeneration. The rich material of ascidia, hydrozoa, and planaria lured numerous researchers to the Zoological Station; only a few of the outstanding scholars could be named here.

Not only zoologists, but the botanists, who worked along with developmental physiologists in Naples, also had caught the regeneration fever. Specifically, the plant physiologist Friedrich Tobler (1879-1957) using filamentous algae, to study the connection between regeneration phenomena and polarity in plants (Tobler, 1902, 1903a, 1903b, 1906). The botanist Hans Winkler (1877-1944) transferred Loeb's experiments done on *Tubularia* species to the green alga *Bryopsis* and found that fragments of its filament behaved just like pieces of hydrocaulus of *Tubularia* (Winkler, 1900).

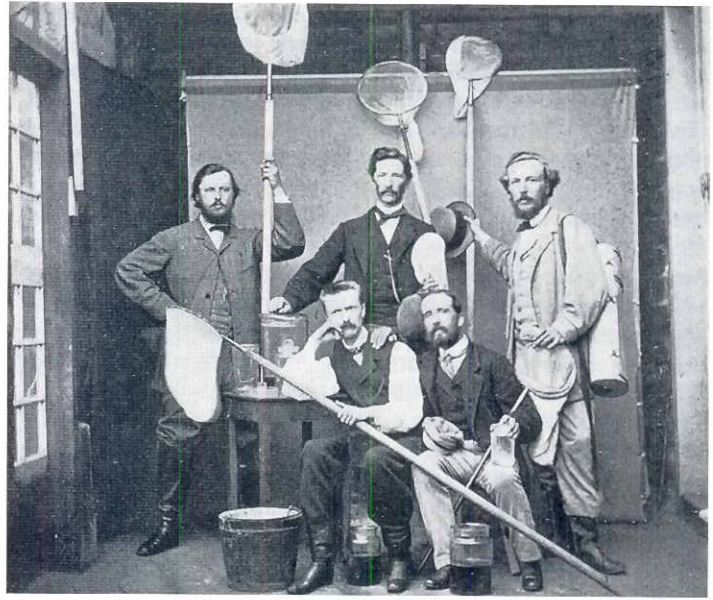
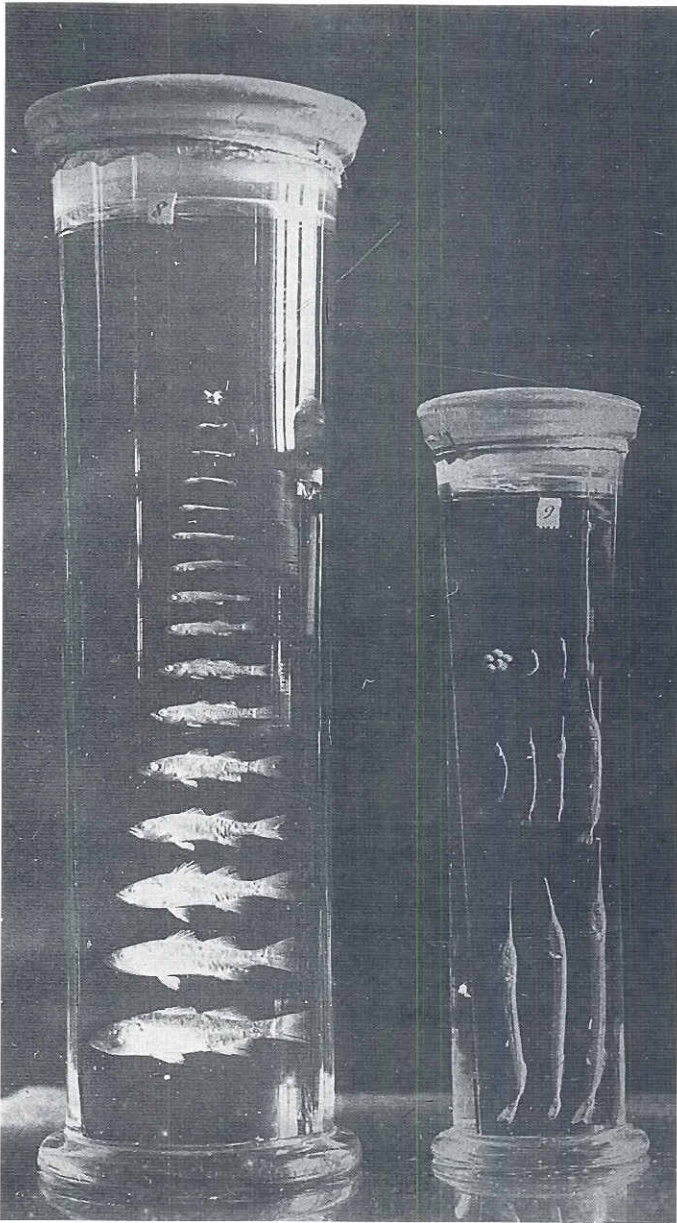


Fig. 5 (Left). Preserved sea animals from the time of S. Lobianco.

Fig. 6 (Top). Meeting of the Zoology Doctorate Students on Helgoland in September 1865 (from the left, standing Anton Dohrn, Richard Greeff, 1829-1892, and Ernst Haeckel, 1834-1919).

Fig. 7 (Bottom). Scaphander, about 1880, a diving apparatus for collecting the animals for which the dredge was unsuitable.

Species of *Tubularia* also served as study material for the already-mentioned biologist Thomas Morgan, who came to Naples to investigate these hydromedusae in search of factors that, according to Loeb's theory, would inhibit the formation of hydroid (Morgan, 1906). However, after additional numerous experiments and also work on planarian regeneration it seemed to him that the solution of the regeneration problem was hopeless (Morgan, 1907). Therefore, he gave up this area of research around the turn of the century and moved over to genetics, a field in which he made his most important discoveries, as is well known.

Loeb's special interest in morphogenetic substances, which he presumed to be the trigger of regenerative reactions, led American zoologist Charles Manning Child (1869-1954) (Child, 1911, 1914) to the Zoological Station. Based on the experiments

that he performed in Naples, he arrived at the theory of the axial gradient, still valid to this day, which proposed that the capacity of morphogenesis of an organism is realized in quantitative steps or values along the body axis, such that a certain gradient of differentiation can be assumed to exist along the body axis. Earlier, Boveri had arrived at a similar assumption (Boveri, 1901), and it cannot be excluded that Child got his idea from Boveri. However, Child went far beyond Boveri's assumption in his attempt to explain gradients on the basis of physiological metabolism.

Although Loeb's regeneration experiments had generated much admiration, his experiments on artificial fertilization — parthenogenesis — caused even more excitement. Loeb discovered in 1900 that for the sea urchin egg the activating effect of the sperm could be substituted by exposure to butyric acid or an increase in osmotic pressure by adding sodium chloride,

thereby triggering the egg to undergo chemical parthenogenesis (Loeb, 1900). Loeb's discovery had been theoretically prepared by the already mentioned zoologist Kurt Herbst of Heidelberg, whom he met in Naples on several occasions. Herbst had observed in 1893 that various chemical substances like clove oil and oil, toluene, benzene, and creosote induced an effect on unfertilized eggs that was similar to that triggered by the penetrating sperm (1893). However, he did not follow up on this observation. Loeb, who repeated this experiment with frogs and has been since known as "father of the fatherless frogs" stated with satisfaction that "the proof of replacement of the mysterious vital agent 'spermatozoon' by the physico-chemical agent 'increase of sea water concentration' . . . liberated the field of fertilization from vitalistic mysticism" (Loeb, 1912).

As demonstrated by this quotation, the problem of the fertilization process shifted more and more from a domain of morphology to physical chemistry and biochemistry (Loeb, 1909, preface). Loeb's further studies consequently led to the investigation of membrane potentials, and to protein and colloid research (1906, 1924) which he, however, no longer pursued in Europe. To avoid the increasing militaristic and anti-Semitic tendencies in the German empire, Loeb, the son of a Jewish merchant emigrated to America after the turn of the century, where he became not only a leading representative of experimental biology. But along with cell biologist Wilson, he was instrumental in spreading the experimental methods of embryology among the American biologists.

Important building blocks for the mechanistic concept of the organism, which Loeb pursued into ever-finer detail, were also supplied by the already-mentioned Kurt Herbst, who also counted among the regular visitors to the Zoological Station. He made the remarkable discovery that animal and vegetal regions of the embryo reacted to certain reagents with characteristic developmental anomalies and growth inhibitions or promotions. This suggested special metabolic conditions along the animal-vegetal polarity axis, but without knowledge of the molecular processes, these could not be unraveled (1897, 1898). An important step toward their explanation was the measurement of oxygen consumption of the sea urchin egg in 1908 in Naples by Otto Heinrich Warburg (1883-1970), who owed his crucial idea of exploring biological oxidation to Loeb (Werner, 1995). He gave the first definitive account of chemical processes accompanying cell division by determining oxygen consumption before and after fertilization of the sea urchin egg. These experiments led to the important discovery that respiration increased six-fold above the basal level following fertilization. Warburg succeeded furthermore in demonstrating trace amounts of iron in sea urchin eggs. For this issue, Kurt Herbst had again supplied important preliminary evidence, as he had demonstrated experimentally already in 1898 that iron was essential for the development of the larval state (1909). Warburg, in his follow up studies of respiration, could unequivocally confirm that iron indeed played a key role in cellular respiration. His further studies eventually led to the discovery of the respiration enzyme cytochrome oxidase, for which he was awarded the Nobel Prize in 1931.

In conclusion, after reviewing the partial listing in this article of results obtained in the fields of experimental physiology and embryology, we are left with an apparently paradoxical phenomenon: Anton Dohrn, although he cleared the way for experimen-

tal embryology with his own creation, the Zoological Station, personally remained a descriptive morphologist. He himself made little use of the means and possibilities which he made available to numerous researchers in Naples.

If, however, the Zoological Station became the focal point of the new research direction of experimental embryology, which revolutionized all of biology, the driving force could not have been Dohrn's own research areas and methods. More likely, the reason can be found in Dohrn's very own personality, in his extraordinary capacity as a research organizer and manager on the one hand, and his function as catalyst for the generation and the communication of ideas on the other. He had a reliable instinct for detecting the genius in others and the significance of their discoveries. Dohrn's achievements therefore go far beyond the mere implementation of a new direction of research rooted in Darwin's theory, or making available excellent working conditions (Müller, 1976): in view of the scientific enterprise expanding at all levels and the increase in scientific data, Dohrn created a new way to organize communication of knowledge. Based on its combined international and interdisciplinary structure, it supported the instantaneous exchange of knowledge among scholars, better than in any other institution. Moreover, it substituted the loss of information, that goes along with an increasing rate of publication, with personal contacts and collaboration. Theodor Boveri's well-known epithet has characterized the Naples institution with precision and brevity: "permanent congress of zoologists".

(The original German version of this article has been translated to the best of his limited capabilities by Helmut W. Sauer, College Station, Texas and typed by his daughter Heidi. During this challenge, unforgettable good memories of the Stazione Zoologica surfaced regarding participation as a young graduate student F. Seidel, Marburg, in the 60's at his first international workshop organized by G. Reverberi, J. Runnström, and J. Brachet, and concerned with subcellular organization of early embryos and funded by the NATO).

References

- BALTZER, F. (1962). *Theodor Boveri. Leben und Werk eines großen Biologen 1862-1915*. Große Naturforscher, Bd.25, Stuttgart.
- BALTZER, F. (1963). Theodor Boveri und die Entwicklung der Chromosomentheorie der Vererbung. *Naturwissenschaften* 50: 141-146.
- BOVERI, T. (1889). Ueber partielle Befruchtung. *S. ber. Ges. Morph. München* 4: 64-72.
- BOVERI, T. (1890). Ein geschlechtlich erzeugter Organismus ohne mütterliche Eigenschaften. *S. ber. Ges. Morph. München* 5: 73-80.
- BOVERI, T. (1891). Ueber die Niere des Amphioxus. *S. ber. Ges. Morph. München* 6: 65-77.
- BOVERI, T. (1901a). Ueber die Polarität des Seeigeleies. *Verh. Phys.-Med. Ges. Würzburg* 34: 145-176.
- BOVERI, T. (1901b). Die Polarität von Oocyte, Ei und Larve des Strongylocentrotus lividus. *Zool. Jb. (Abt. Anat. Ont.)* 14: 630-653.
- BOVERI, T. (1903). Ueber mehrpolige Mitosen als Mittel zur Analyse des Zellkerns. *Verh. Phys.-Med. Ges. Würzburg* 35 (N.F.): 67-90.
- CHILD, C.M. (1911). *Die physiologische Isolation von Teilen des Organismus als Auslösfaktor der Bildung neuer Lebewesen und der Restitution*. Leipzig (=Vorträge und Aufsätze über Entwicklungs-Mechanik, Hrg.v.W.Roux, H.11)
- CHILD, C.M. (1914). Susceptibility Gradients in Animals. *Science* 39: 73-76.
- CREMER, T. (1985). *Von der Zellenlehre zur Chromosomentheorie. Naturwissenschaftliche Erkenntnis und Theorienwechsel in der frühen Zell- und Vererbungsforschung*. Springer, Berlin.

- DRIESCH, H. (1890/91). Tektonische Studien an Hydroidpolypen. I. Die Campanulariden und Sertulariden. II. Plumularia und Aglaophenia. Die Tubulariden. III. Antennularia. *Zschr. Med. Naturw.* 24 (N.F.17): 189-224; 657-688; 25 (N.F.18): 467-479.
- DRIESCH, H. (1891). Entwicklungsmechanische Studien. I. Der Werth der beiden ersten Furchungszellen in der Echinodermen-Entwicklung. Experimentelle Erzeugung von Theil- und Doppelbildungen. *Zschr. wiss.Zool.* 53: 160-177.
- DRIESCH, H. (1893a). Entwicklungsmechanische Studien III-VI. *Zschr. wiss. Zool.* 55: 1-62.
- DRIESCH, H. (1893b). Entwicklungsmechanische Studien III. Die Verminderung des Furchungsmaterials und ihre Folgen (Weiteres über Theilbildungen). IV. Experimentelle Veränderungen des Typus der Furchung und ihre Folgen (Wirkungen von Wärmezufuhr und von Druck). V. Von der Furchung doppelt befruchteter Eier. VI. Über einige allgemeine Fragen der theoretischen Morphologie. *Zschr. wiss. Zool.* 55: 1-62.
- DRIESCH, H. (1899). Die Lokalisation morphogenetischer Vorgänge. Ein Beweis vitalistischen Geschehens. *W. Roux Arch. Entw.-Mech. Org.* 8: 35-111.
- DRIESCH, H. (1905). *Der Vitalismus als Geschichte und als Lehre.* J.A. Barth, Leipzig.
- DRIESCH, H. (1909). *Philosophie des Organischen*, 2 Bde. Wilhelm Engelmann, Leipzig.
- DRIESCH, H. (1951). *Lebenserinnerungen.* München.
- GROEBEN, C. (1982). *Charles Darwin (1809-1882)-Anton Dohrn (1840-1909).* Macchiarol, Neapel.
- HERBST, C. (1893). Ueber die künstliche Hervorrufung von Dottermembranen an unbefruchteten Seeigeleiern, nebst einigen Bemerkungen über die Dotterhautbildung überhaupt. *Biol. Zbl.* 13: 14-22.
- HERBST, C. (1897). Über die zur Entwicklung von Seeigellarven notwendigen anorganischen Stoffe, ihre Rolle und ihre Vertretbarkeit. I. Die zur Entwicklung notwendigen anorganischen Stoffe. *W. Roux Arch. Entw.-Mech. Org.* 5: 649-793.
- HERBST, C. (1898). Über zwei Fehlerquellen beim Nachweis der Unentbehrlichkeit von Phosphor und Eisen für die Entwicklung der Seeigellarven. *W. Roux Arch. Entw.-Mech. Org.* 7: 486-510.
- HERBST, C. (1900). Über das Auseinandergehen von Furchungs- und Gewebezellen in kalkfreiem Medium. *W. Roux Arch. Entw.-Mech. Org.* 9: 424-463, Taf. 18-19.
- HERBST, C. (1924). Jacques Loeb. Eine kurzer Überblick über sein Lebenswerk. *Naturwissenschaften* 12: 397-406.
- HERTWIG, O. (1875). Beiträge zur Kenntnis der Bildung, Befruchtung und Theilung des thierischen Eies. *Gegenbaurs morph. Jb.* 1: 347-434T.
- HEUSS, T.(1962). *Anton Dohrn.* Wunderlich Verlag, Tübingen.
- KÜHN, A. (1950). Anton Dohrn und die Zoologie seiner Zeit. *Pubb. Staz. Zool. Napoli (Suppl.)*: 1-205.
- LOEB, J. (1890). Weitere Untersuchungen über den Heliotropismus der Thiere und seine Übereinstimmung mit dem Heliotropismus der Pflanzen (Heliotropische Krümmungen bei Thieren). *Pflügers Arch. ges. Physiol.* 47: 391-416.
- LOEB, J. (1891). *Untersuchungen zur physiologischen Morphologie der Thiere. I. Ueber Heteromorphose.* G. Hertz, Würzburg.
- LOEB, J. (1892). *II. Organbildung und Wachstum.* G. Hertz, Würzburg.
- LOEB, J. (1900). On the nature of the Process of fertilization and the artificial production of normal larvae (Plutei) from the unfertilized eggs of the Seaurchin. *Am. J. Physiol.* 3: 135-138.
- LOEB, J. (1906). *Vorlesungen über die Dynamik der Lebenserscheinungen.* J.A. Barth, Leipzig.
- LOEB, J. (1909). *Die chemische Entwicklungserregung des tierischen Eies (Künstliche Parthenogenese).* Springer, Berlin.
- LOEB, J. (1912). Das Leben (Vortrag). In Der erste internationale Monisten-Kongreß in Hamburg, 8-11 September, 1911. W. Bloßfeldt, Leipzig, pp.77-93.
- LOEB, J. (1916). *The Organisms as a Whole. From the Physicochemical Viewpoint.* G.P. Putnam's sons, New York, p.153.
- LOEB, J. (1924). *Die Eiweißkörper und die Theorie der kolloidalen Erscheinungen.* Springer, Berlin.
- MOCEK, R. (1974). *Wilhelm Roux-Hans Driesch. Zur Geschichte der Entwicklungsphysiologie der Tiere ("Entwicklungsmechanik").* Gustav Fischer Verlag, Jena (=Biographien bedeutender Biologen, 1).
- MORGAN, T. (1896). A study of variation in cleavage. *W. Roux Arch. Entw.-Mech. Org.* 2: 72-80 (Taf. 10).
- MORGAN, T.H. (1906). Hydranth Formation and Polarity in Tubularia. *J. Exp. Zool.* 3: 501.
- MORGAN, T.H. (1907). *Regeneration.* Deutsch von M. Moszkowski, Leipzig.
- MÜLLER, I. (1973). Der 'Hydriot' Nikolai Kleinenberg oder: Spekulation und Beobachtung. *Med. Hist. J.* 8: 131-153.
- MÜLLER, I. (1975a). One hundred years of the Zoological Station in the service of international research. In *The Naples Zoological Station at the Time of Anton Dohrn. Exhibition and Catalogue* (Eds. C. Groeben and I. Müller). Naples Zoological Station, Naples.
- MÜLLER, I. (1975b). Die Wandlung embryologischer Forschung von der deskriptiven zur experimentellen Phase unter dem Einfluß der Zoologischen Station in Neapel. *Med. Hist. J.* 10: 191-218.
- MÜLLER, I. (1976). *Die Geschichte der Zoologischen Station in Neapel von der Gründung durch Anton Dohrn (1872) bis zum Ersten Weltkrieg und ihre Bedeutung für die Entwicklung der modernen biologischen Wissenschaften.* Habilitationsschrift, Universität Düsseldorf, Düsseldorf.
- MÜLLER, I. (1994). Degeneration als Prinzip der Wirbeltier-Phylogenie. Ein Kapitel aus der Geschichte der Evolutionstheorie. In *Miscellen zur Geschichte der Biologie* (Ed. A.Geus). Forschungsinstitut und Naturmuseum Senckenberg, Frankfurt a.M., pp.117-135.
- PARTSCH, K.J. (1980). *Die Zoologische Station in Neapel.* Modell internationaler Wissenschaftszusammenarbeit. Vandenhoeck u. Ruprecht, Göttingen.
- PAULY,P.J. (1987). *Controlling Life: Jacques Loeb and the Engineering Ideal in Biology.* Oxford University Press, New York.
- RÖNTGEN, W.C. (1918) (Hrg.). *Erinnerungen an Theodor Boveri.* J.C.B. Mohr, Tübingen.
- ROUX, W. (1889). *Die Entwicklungsmechanik der Organismen, eine anatomische Wissenschaft der Zukunft.* Festrede, Vienna.
- SPEMANN, H. (1923). Mikrochirurgische Operationstechnik. In *Handbuch der biologischen Arbeitsmethoden.* Hrg. v. E. Abderhalden, Abt.5, T.3, Berlin, S.2-30
- TOBLER, F. (1902). Zerfall und Reproduktionsvermögen des Thallus einer Rhodomelacee. *Ber. dtsh. bot. Ges.* 20: 357-365.
- TOBLER, F. (1903a). Ueber Eigenwachstum der Zelle und Pflanzenform. Versuche und Studien an Meeressalgen. *Jb. Wiss. Bot.* 39: 527-580.
- TOBLER, F. (1903b). Ueber Polymorphismus von Meeressalgen. Beiträge zur Kenntnis des Eigenwachstums der Zelle. *S. B. preuss. Akad. Wiss.* 18: 372-384.
- TOBLER, F. (1906). Über Regeneration und Polarität sowie verwandte Wachstumsvorgänge bei Polysiphonia und anderen Algen. *Jb. wiss. Bot.* 42: 461-502.
- UBISCH, L.v. (1954/58). Über Seeigelmerogone. *Pubbl. Staz. Zool. Napoli* 25 (1954): 245-338; 30 (1957/58): 279-308.
- WARBURG, O. (1908). Beobachtungen über die Oxydationsprozesse im Seeigelei. *Hoppe Seyler's Z. physiol. Chem.* 57: 1-16.
- WERNER, P. (1995). Otto Warburg, Jacques Loeb und die Entstehung der Institutsidee des Kaiser-Wilhelm-Instituts für Zellphysiologie. *J. Hist. Biol.* (In press).
- WILSON, E.B. (1889). The embryology of the earthworm. *J. Morphol.* 3: 387-462.
- WILSON, E.B. (1893). Amphioxus and the mosaic theory of development. *J. Morphol.* 8: 579-638.
- WILSON, E.B. (1896). *The Cell in Development and Heredity.* Macmillan Company, New York.
- WILSON, E.B. (1904a). Experimental studies on germinal localization. I. The germ-regions in the egg of Dentalium. *J. Exp. Zool.* 1: 1-72.
- WILSON, E.B. (1904b).II. Experiments on the cleavage-mosaic in Patella and Dentalium. *J. Exp. Zool.* 1: 197-268.
- WILSON,E.B. (1905). The chromosomes in relation to determination of sex in insects. *Science* 22: 500-502.
- WINKLER, H. (1900). Über Polarität, Regeneration und Heteromorphose bei Bryopsis. *Jb. wiss. Bot.* 35: 449-469.