

Endoderm ^[1]

By: MacCord, Kate Keywords: mesendoderm ^[2]

Endoderm is one of the germ layers?aggregates of cells that organize early during embryonic life and from which all organs and tissues develop. All animals, with the exception of sponges, form either two or three [germ layers](#) ^[3] through a process known as [gastrulation](#) ^[4]. During [gastrulation](#) ^[4], a ball of cells transforms into a two-layered embryo made of an inner layer of [endoderm](#) ^[5] and an outer layer of [ectoderm](#) ^[6]. In more complex organisms, like vertebrates, these two primary [germ layers](#) ^[3] interact to give rise to a third germ layer, called [mesoderm](#) ^[7]. Regardless of the presence of two or three layers, [endoderm](#) ^[5] is always the inner-most layer. Endoderm forms the epithelium?a type of tissue in which the cells are tightly linked together to form sheets?that lines the primitive gut. From this epithelial lining of the primitive gut, organs like the digestive tract, liver, pancreas, and lungs develop.

Throughout the early stages of [gastrulation](#) ^[4], a group of cells called mesendoderm expresses sets of both [endoderm](#) ^[5]- and [mesoderm](#) ^[7]-specific [genes](#) ^[8]. Cells in the mesendoderm have the ability to differentiate into either [mesoderm](#) ^[7] or [endoderm](#) ^[5], depending upon their position among surrounding cells. Scientists have found mesendoderm is widespread among invertebrates, including the nematode *Caenorhabditis elegans* ^[9], and the purple [sea urchin](#) ^[10], *Strongylocentrotus purpuratus* ^[11]. Within vertebrates, mesendoderm has been found in the zebrafish, *Danio rerio* ^[12], and has been indicated in mice, *Mus musculus* ^[13].

Endoderm, along with the other two [germ layers](#) ^[3], was discovered in 1817 by Christian Pander, a doctoral student at the [University of Würzburg](#) ^[14], in Würzburg, Germany. In his dissertation, *Beiträge zur Entwicklungsgeschichte des Hühnchens im Eie* (*Contributions to the Developmental History of the Chicken in the Egg*), Pander described how two layers give rise to a third in the [chick](#) ^[15] (*Gallus gallus* ^[16]) embryo. Pander's description of the formation of these layers is the first account of [gastrulation](#) ^[4] in the [chick](#) ^[15], and it grounded future studies of the [germ layers](#) ^[3]. Martin Rathke at the University of Königsberg, in Königsberg, Prussia (later Poland), soon found evidence in a developing [crayfish](#) ^[17], *Astacus astacus* ^[18], of the two layers Pander had described. Rathke's finding marked the first discovery of [endoderm](#) ^[5] and [ectoderm](#) ^[6] in an invertebrate, but that information was not further investigated for two decades.

The [germ layers](#) ^[3] drew the attention of many scientists in the nineteenth century. [Karl Ernst von Baer](#) ^[19] at the University of Königsberg, extended the concept of [germ layers](#) ^[3] to include all vertebrates in his 1828 text *Über die Entwicklungsgeschichte der Thiere. Beobachtung und Reflexion* (*On the Developmental History of the Animals. Observations and Reflections*). Twenty years later, natural historian [Thomas Henry Huxley](#) ^[20], in England, applied Pander's concept of [germ layers](#) ^[3] to jellyfish. In his 1849 paper "On the Anatomy and Affinities of the Family of the Medusae," Huxley noted that the two layers of cells he saw in the adult jellyfish related to each other the same way as the [germ layers](#) ^[3] in [chick](#) ^[15] embryos described by Pander. The association that Huxley made between the body plan of the adult jellyfish and the

vertebrate embryo connected the study of growth and development, called [ontogeny](#) [21], to the study of relationships between organisms, called [phylogeny](#) [22]. Huxley's support for a relationship between [ontogeny](#) [21] and [phylogeny](#) [22], later known as the theory of recapitulation, would become fundamental to the works of late nineteenth century scientists, like [Charles Darwin](#) [23], in England, and [Ernst Haeckel](#) [24] at the [University of Jena](#) [25], in Jena, Germany. These and other scientists began to look to embryos for evidence of [evolution](#) [26].

By the 1860s researchers compared [germ layers](#) [3] across the animal kingdom. Beginning in 1864 embryologist Aleksandr Kovalevsky, who studied [embryology](#) [27] at the University of St. Petersburg, in St. Petersburg, Russia, studied invertebrates. His research showed that invertebrate embryos had the same primary [germ layers](#) [3], [endoderm](#) [5] and [ectoderm](#) [6], as vertebrate embryos, and that the layers arose in the same fashion across the animal kingdom. Kovalevsky's findings convinced many about the universality of the germ layers—a result that some scientists made a principle of germ layer theory. Germ layer theory held that each of the [germ layers](#) [3], regardless of species, gave rise to a fixed set of organs. These organs were deemed homologous across the animal kingdom, effectively uniting [ontogeny](#) [21] with [phylogeny](#) [22]. Scientists like Haeckel in Germany and [Edwin Ray Lankester](#) [28] at the [University College](#) [29], London, in London, England convinced many to accept germ layer theory by the end of the nineteenth century.

While germ layer theory garnered broad support, not everyone accepted it. Beginning in the late nineteenth century, embryologists such as [Edmund Beecher Wilson](#) [30], in the United States, and [Wilhelm His](#) [31] and Rudolf [Albert von Kölliker](#) [32], both in Germany, objected to the absolute universality of the [germ layers](#) [3] that the theory demanded. These opponents of germ layer theory belonged mainly to a new tradition of embryologist—those who used physical manipulations of embryos to research development. By the 1920s, experiments by scientists like [Hans Spemann](#) [33] and [Hilde Mangold](#) [34], in Germany, and Sven Hörstadius, in Sweden, led scientists to dismantle the germ layer theory.

Early twentieth-century scientists sought to explain the [germ layers](#) [3] more fully by investigating how embryos transformed from one cell to thousands of cells. Among these embryologists, [Edwin Grant Conklin](#) [35] at the [University of Pennsylvania](#) [36], in Philadelphia, Pennsylvania, was one of the first to trace cell lineages from the single-cell stage. In his 1905 text *The Organization and Cell-lineage of the Ascidian Egg*, Conklin mapped the divisions and subsequent specialization of the cells in the embryo of an ascidian, or sea squirt, a type of marine invertebrate that develops a tough outer layer and clings to the sea floor. By creating a plot, or fate map, of the developmental route of each of the cells, Conklin located the precursor cells, traced the formation of each of the [germ layers](#) [3], and showed that even at very early stages of development, the ability of some cells to differentiate becomes restricted.

Conklin's [fate mapping](#) [37] experiments, along with questions about the capacity of cells to differentiate, influenced scientists like Robert Briggs, at [Indiana University](#) [38] in Bloomington, Indiana, and his collaborator, Thomas King, at the [Institute for Cancer Research](#) [39] in Philadelphia, Pennsylvania. In the 1950s Briggs and King began a series of experiments to test the developmental capacity of cells and embryos. In 1957 Briggs and King transplanted nuclei from the presumptive [endoderm](#) [5] of the northern leopard [frog](#) [40], *Rana pipiens* [41], into eggs from which they had removed the nuclei. This technique, which Briggs and King helped create, called [nuclear transplantation](#) [42], allowed them to explore the timing of cell [differentiation](#) [43], and the technique became a basis for future experiments in [cloning](#) [44]. From their [nuclear transplantation](#) [42] experiments, Briggs and King found that during

endodermal [differentiation](#) [43], the ability of the [nucleus](#) [45] to help cells specialize becomes progressively restricted. That result was supported in 1960 by the work of [John Gurdon](#) [46], at Oxford University in Oxford, England. Gurdon recreated Briggs and King's experiments using the African clawed [frog](#) [40], *Xenopus laevis* [47], and Gurdon found that there are significant differences between species in the rate and timing of onset of these endodermal restrictions.

While Briggs, King, and Gurdon worked to understand the restriction of endodermal cell fates, other scientists, like Pieter Nieuwkoop, at the Royal Netherlands Academy of Arts and Science, in Utrecht, Holland, investigated the formation of the [germ layers](#) [3]. In 1969 Nieuwkoop published an article, "The Formation of the Mesoderm in Urodelean Amphibians. I. Induction by the Endoderm," in which he examined the interactions of the [endoderm](#) [5] and [ectoderm](#) [6]. Nieuwkoop divided embryos of the [salamander](#) [48], *Ambystoma mexicanum* [49], into regions of presumptive [endoderm](#) [5] and presumptive [ectoderm](#) [6]. When left to develop in isolation, [mesoderm](#) [7] did not form. But when he recombined the two tissues, the [endoderm](#) [5] induced the formation of [mesoderm](#) [7] in adjacent regions of the [ectoderm](#) [6].

Although scientists had traced the fate of the [endoderm](#) [5], investigated the capacity of endodermal cells to differentiate, and had examined the [induction](#) [50] potential of said cells, they did not investigate the molecular pathways that specify and pattern the [endoderm](#) [5] until the 1990s. From these studies emerged the theory that maternal signals, or developmental effects that the mother contributes to the [egg](#) [51] prior to [fertilization](#) [52], act through three main families of protein-coding [genes](#) [8] to help regulate the early [differentiation](#) [43] of [endoderm](#) [5]. These signals are proteins β -catenin, VegT, and Otx. The molecular pathways involved in later stages of [endoderm](#) [5] [differentiation](#) [43] and patterning are different across species, especially the transcription factors, or proteins that help regulate gene expression. GATA factors in particular are expressed in mesendoderm and are necessary for the [endoderm](#) [5] to differentiate. While there are some genetic elements conserved across the animal kingdom, like β -catenin, some portions of the [endoderm](#) [5] [induction](#) [50] pathway, especially signals like the proteins Nodal and Wnt, are vertebrate-specific. In 2002 [Eric Davidson](#) [53] and his colleagues at [California Institute of Technology](#) [54] in Pasadena, California, announced the full network of [genes](#) [8] that regulate the specification of [endoderm](#) [5] and [mesoderm](#) [7] in sea urchins in their paper, "A Genomic Regulatory Network for Development." Davidson confirmed that network of [genes](#) [8] in a co-authored article published in 2012.

Sources

1. von Baer, Karl Ernst. *Über Entwicklungsgeschichte der Thiere. Beobachtung und Reflexion* [On the Developmental History of Animals. Observation and Reflection]. Königsberg: Bornträger, 1828.
<http://babel.hathitrust.org/cgi/pt?id=inu.32000003298751;page=root;view=1up;size=100;seq=7;ori>
[55] (Accessed October 3, 2012).
2. Briggs, Robert, and Thomas King. "Changes in the Nuclei of Differentiating Endoderm Cells as Revealed by Nuclear Transplantation." *Journal of Morphology* [56] 100 (1957): 269-311.
3. Briggs, Robert and Thomas King. "Nuclear Transplantation Studies on the Early Gastrula (*Rana pipiens* [57]) I. Nuclei of Presumptive Endoderm." *Developmental Biology* [58] 2 (1960): 252-70.
4. Conklin, Edwin Grant. *The Organization and Cell-lineage of the Ascidian Egg*.

Philadelphia: [Academy of Natural Sciences](#) [59], 1905.

<http://www.biodiversitylibrary.org/ia/organizationcell00conk> [60] (Accessed October 8, 2012).

5. Damle, Sagar, and [Eric Davidson](#) [53]. "Synthetic [in vivo](#) [61] Validation of Gene Network Circuitry." *Proceedings of the National Academy of Sciences* [62] 109 (2012): 1548?53.
6. Darwin, Charles. *On the Origin of Species by Means of Natural Selection*. London: Murray, 1859. <http://darwin-online.org.uk/content/frameset?pageseq=1&itemID=F373&viewtype=text> [63] (Accessed November 4, 2013).
7. Davidson, Eric H., Jonathan P. Rast, Paola Oliveri, Andrew Ransick, Cristina Calestani, Chiou-HwaYuh, Takuya Minokawa, Gabriele Amore, Veronica Hinman, César Arenas-Mena, Ochan Otim, C. Titus Brown, Carolina B. Livi, Pei Yun Lee, Roger Revilla, Alistair G. Rust, Zheng jun Pan, Maria J. Schilstra, Peter J. C. Clarke, Maria I. Arnone, Lee Rowen, R. Andrew Cameron, David R. McClay, Leroy Hood, Hamid Bolouri. "A Genomic Regulatory Network for Development." *Science* 295 (2002): 1669?1678.
8. Gilbert, Scott. *Developmental Biology* [58]. Massachusetts: Sinauer, 2006.
9. Grapin-Botton, Anne, and Daniel Constam. "Evolution of the Mechanisms and Molecular Control of Endoderm Formation." *Mechanisms of Development* 124 (2007): 253?278.
10. Gurdon, John. "The Developmental Capacity of Nuclei Taken from Differentiating Endoderm Cells of [Xenopus laevis](#) [64]." *Journal of Embryology and Experimental Morphology* 8 (1960): 505?26.
11. Haeckel, Ernst. "Die Gastraea-Theorie, die phylogenetische Classification des Thierreichs und die Homologie der Keimblätter" [The Gastraea Theory, the Phylogenetic Classification of the Animal Kingdom and the [Homology](#) [65] of the Germ Layers]. In *Jenaische Zeitschrift für Naturwissenschaft*, 8 (1874): 1?55.
12. Hall, Brian Keith. "Germ Layers and the Germ Layer Theory Revisited." *Evolutionary Biology* 30 (1998): 121?86.
13. Hertwig, Oscar and Richard Hertwig. *Studien zur Blätter theorie. Heft I. Die Actinien anatomisch und histologisch mit besonderer Berücksichtigung des Nerven-muskelsystems untersucht* [Studies of Layer Theory. Part I. The Anatomy and Histology of the Actinia, with special reference to the neuro-muscular system]. Jena: Fischer, 1879. <http://dx.doi.org/10.5962/bhl.title.15278> [66] (Accessed November 4, 2013).
14. His, Wilhelm. *Untersuchungen über die erste Anlage des Wirbelthierleibes: Die erste Entwicklung des Hühnchens im Ei* [Studies on the first system of the vertebrate body: The first Development of the [chick](#) [15] in the [egg](#) [51]]. [Leipzig](#) [67]: F.C.W. Vogel, 1868. <http://www.biodiversitylibrary.org/ia/untersuchungen1868hisw> [68] (Accessed October 8, 2012).
15. Hörstadius, Sven. "Über die Determination des Keimes bei Echinodermen" [Determination of the [germ layers](#) [3] in Echinoderms]. *Acta Zoologica* 9 (1928): 1?191.
16. Hörstadius, Sven. "Über die Determination im Verlaufe der Eiachse bei Seeigeln." [Determination During the Egg Axis in Sea Urchins]. *Pubblicazioni della [Stazione Zoologica](#) [69] di Napoli* 14 (1935): 251?429.
17. Huxley, Thomas Henry. "On the Anatomy and Affinities of the Family of the Medusae." *Philosophical Transactions of the Royal Society of London* 139 (1849): 413?34. <http://archive.org/stream/philtrans02516543/02516543#page/n0/mode/2up> [70] (Accessed October 8, 2012).
18. Kimelman, D, and C. Bjornson. "Vertebrate Mesoderm Induction: From Frogs to Mice." In *Gastrulation: From Cells to Embryo*, ed. Stern, Claudio D. [Cold Spring Harbor Laboratory](#) [71] Press: 2004.

19. Kölliker, Albert. "Die Embryonalen Keimblätter und die Gewebe" [The Embryonic Germ Layers and Tissues]. *Zeit. Wiss. Zool.* 40 (1884): 179-213.
20. Kovalevsky, Aleksandr. "Entwicklungsgeschichte des *Amphioxus lanceolatus* [On the Development of *Amphioxus lanceolatus*]." *Memoires de Academie Imperiale des Sciences de St. Petersbourg XI* (1867) Translated and published in *Annals and Magazine of Natural History* 3 (1867): 69-70.
<http://www.biodiversitylibrary.org/page/22192905#page/83/mode/1up> [72] (Accessed October 3, 2012).
21. Lankester, Edwin Ray. "On the Primitive Cell-Layers of the Embryo as the Basis of Genealogical Classification of Animals, and on the Origin of Vascular and Lymph Systems." *The Annals and Magazine of Natural History* 4 (1873): 321-38.
22. Nieuwkoop, Pieter D. "The Formation of the Mesoderm in Urodelean Amphibians. I. Induction by the Endoderm." *Roux' Archiv Entwicklungsmechanik* [73] *der Organismen* 160 (1969): 341-73.
23. Oppenheimer, Jane. "The Non-Specificity of the Germ-Layers." *The Quarterly Review of Biology* [74] 15 (1940): 1-27.
24. Oppenheimer, Jane, and Viktor Hamburger [75]. "The Non-Specificity of the Germ-Layers." *The Quarterly Review of Biology* [74] 51 (1976): 96-124.
25. Pander, Christian. *Beiträge zur Entwicklungsgeschichte des Hühnchens im Eie* [Contributions to the Developmental History of the Chicken in the Egg]. Würzburg: 1817.
<http://echo.mpiwg-berlin.mpg.de/ECHOdocuView?mode=imagepath&url=/mpiwg/online/permanent/library/TAQKCW/> [76] (Accessed October 3, 2012).
26. Spemann, Hans, and Hilde Mangold [34]. *Über Induktion von Embryonalanlagen durch Implantation artfremder Organisatoren* [On the Induction of Embryonic Primordia by Implantation of Organizers from a Different Species]. Berlin: Springer, 1924.
<http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0CCEQFjAA&url=http://www.mpiwg-berlin.mpg.de/ECHOdocuView?mode=imagepath&url=/mpiwg/online/permanent/library/TAQKCW/> [77]
27. Stainier, Didier. "A Glimpse into the Molecular Entrails of Endoderm Formation." *Genes & Development* 16 (2002): 893-907.
28. Wilson, Edmund Beecher. "*Amphioxus*, and the mosaic theory of development." *Journal of Morphology* [56] 8 (1893): 579-638.

Endoderm is one of the germ layers-- aggregates of cells that organize early during embryonic life and from which all organs and tissues develop. All animals, with the exception of sponges, form either two or three germ layers through a process known as gastrulation. During gastrulation, a ball of cells transforms into a two-layered embryo made of an inner layer of endoderm and an outer layer of ectoderm. In more complex organisms, like vertebrates, these two primary germ layers interact to give rise to a third germ layer, called mesoderm. Regardless of the presence of two or three layers, endoderm is always the inner-most layer. Endoderm forms the epithelium-- a type of tissue in which the cells are tightly linked together to form sheets-- that lines the primitive gut. From this epithelial lining of the primitive gut, organs like the digestive tract, liver, pancreas, and lungs develop.

Subject

Gastrulation [78] Embryos [79] Embryology [80] Cells [81] Tissues [82] Cell differentiation [83] Anatomy [84] Vertebrates [85] invertebrates [86] Embryological development [87] Organs [88] Organs (Anatomy) [89] Pander, Christian Heinrich, 1794-1865 [90] Rathke, Heinrich, 1793-1860 [91] Baer, Karl Ernst von, 1792-1876

[92] Huxley, Thomas Henry, 1825-1895 [93] Lankester, E. Ray (Edwin Ray), Sir, 1847-1929 [94] Haeckel, Ernst, 1834-1919 [95] His, Wilhelm, 1831-1904 [96] Wilson, Edmund B. (Edmund Beecher), 1856-1939 [97] Kölliker, Albert, 1817-1905 [98] Conklin, Edwin Grant, 1863-1952 [99] Spemann, Hans, 1869-1941 [100] Nieuwkoop, Pieter D. (Pieter Dirk) [101] Germ Layers [102] Endoderm [103]

Topic

Processes [104]

Publisher

Arizona State University. School of Life Sciences. Center for Biology and Society. Embryo Project Encyclopedia.

Rights

Copyright Arizona Board of Regents Licensed as Creative Commons Attribution-NonCommercial-Share Alike 3.0 Unported (CC BY-NC-SA 3.0)
<http://creativecommons.org/licenses/by-nc-sa/3.0/>

Format

Articles [105]

Last Modified

Wednesday, July 4, 2018 - 04:40

DC Date Accessioned

Sunday, November 17, 2013 - 17:47

DC Date Available

Sunday, November 17, 2013 - 17:47

DC Date Created

2013-11-17

- [Contact Us](#)

© 2018 Arizona Board of Regents

- The Embryo Project at Arizona State University, 1711 South Rural Road, Tempe
Arizona 85287, United States

Source URL: <https://embryo.asu.edu/pages/endoderm>

Links:

[1] <https://embryo.asu.edu/pages/endoderm>
[2] <https://embryo.asu.edu/keywords/mesendoderm>
[3] <https://embryo.asu.edu/search?text=germ%20layers>
[4] <https://embryo.asu.edu/search?text=gastrulation>
[5] <https://embryo.asu.edu/search?text=endoderm>
[6] <https://embryo.asu.edu/search?text=ectoderm>
[7] <https://embryo.asu.edu/search?text=mesoderm>
[8] <https://embryo.asu.edu/search?text=genes>
[9] <http://eol.org/pages/403869/overview>
[10] <https://embryo.asu.edu/search?text=sea%20urchin>
[11] <http://eol.org/pages/598175/overview>
[12] <http://eol.org/pages/204011/overview>
[13] <http://eol.org/pages/328450/overview>
[14] <https://embryo.asu.edu/search?text=University%20of%20W%C3%BCrzburg>
[15] <https://embryo.asu.edu/search?text=chick>
[16] <http://eol.org/pages/1049263/overview>
[17] <https://embryo.asu.edu/search?text=crayfish>
[18] <http://eol.org/pages/1021866/overview>
[19] <https://embryo.asu.edu/search?text=Karl%20Ernst%20von%20Baer>
[20] <https://embryo.asu.edu/search?text=Thomas%20Henry%20Huxley>
[21] <https://embryo.asu.edu/search?text=ontogeny>
[22] <https://embryo.asu.edu/search?text=phylogeny>
[23] <https://embryo.asu.edu/search?text=Charles%20Darwin>
[24] <https://embryo.asu.edu/search?text=Ernst%20Haeckel>
[25] <https://embryo.asu.edu/search?text=University%20of%20Jena>
[26] <https://embryo.asu.edu/search?text=evolution>
[27] <https://embryo.asu.edu/search?text=embryology>
[28] <https://embryo.asu.edu/search?text=Edwin%20Ray%20Lankester>
[29] <https://embryo.asu.edu/search?text=University%20College>
[30] <https://embryo.asu.edu/search?text=Edmund%20Beecher%20Wilson>
[31] <https://embryo.asu.edu/search?text=Wilhelm%20His>
[32] <https://embryo.asu.edu/search?text=Albert%20von%20K%C3%B6lliker>
[33] <https://embryo.asu.edu/search?text=Hans%20Spemann>
[34] <https://embryo.asu.edu/search?text=Hilde%20Mangold>
[35] <https://embryo.asu.edu/search?text=Edwin%20Grant%20Conklin>
[36] <https://embryo.asu.edu/search?text=University%20of%20Pennsylvania>
[37] <https://embryo.asu.edu/search?text=fate%20mapping>
[38] <https://embryo.asu.edu/search?text=Indiana%20University>
[39] <https://embryo.asu.edu/search?text=Institute%20for%20Cancer%20Research>
[40] <https://embryo.asu.edu/search?text=frog>
[41] <http://eol.org/pages/1019093/overview>
[42] <https://embryo.asu.edu/search?text=nuclear%20transplantation>
[43] <https://embryo.asu.edu/search?text=differentiation>
[44] <https://embryo.asu.edu/search?text=cloning>
[45] <https://embryo.asu.edu/search?text=nucleus>
[46] <https://embryo.asu.edu/search?text=John%20Gurdon>
[47] <http://eol.org/pages/1038993/overview>
[48] <https://embryo.asu.edu/search?text=salamander>
[49] <http://eol.org/pages/1019571/overview>
[50] <https://embryo.asu.edu/search?text=induction>
[51] <https://embryo.asu.edu/search?text=egg>
[52] <https://embryo.asu.edu/search?text=fertilization>
[53] <https://embryo.asu.edu/search?text=Eric%20Davidson>
[54] <https://embryo.asu.edu/search?text=California%20Institute%20of%20Technology>
[55] <http://babel.hathitrust.org/cgi/pt?id=inu.32000003298751;page=root;view=1up;size=100;seq=7;orient=0>

[56] <https://embryo.asu.edu/search?text=Journal%20of%20Morphology>
[57] <https://embryo.asu.edu/search?text=Rana%20pipiens>
[58] <https://embryo.asu.edu/search?text=Developmental%20Biology>
[59] <https://embryo.asu.edu/search?text=Academy%20of%20Natural%20Sciences>
[60] <http://www.biodiversitylibrary.org/ia/organizationcell00conk>
[61] <https://embryo.asu.edu/search?text=in%20vivo>
[62] <https://embryo.asu.edu/search?text=National%20Academy%20of%20Sciences>
[63] <http://darwin-online.org.uk/content/frameset?pageseq=1&itemID=F373&viewtype=text>
[64] <https://embryo.asu.edu/search?text=Xenopus%20laevis>
[65] <https://embryo.asu.edu/search?text=Homology>
[66] <http://dx.doi.org/10.5962/bhl.title.15278>
[67] <https://embryo.asu.edu/search?text=Leipzig>
[68] <http://www.biodiversitylibrary.org/ia/untersuchungen1868hisw>
[69] <https://embryo.asu.edu/search?text=Stazione%20Zoologica>
[70] <http://archive.org/stream/philtrans02516543/02516543#page/n0/mode/2up>
[71] <https://embryo.asu.edu/search?text=Cold%20Spring%20Harbor%20Laboratory>
[72] <http://www.biodiversitylibrary.org/page/22192905#page/83/mode/1up>
[73] <https://embryo.asu.edu/search?text=Entwicklungsmechanik>
[74] <https://embryo.asu.edu/search?text=The%20Quarterly%20Review%20of%20Biology>
[75] <https://embryo.asu.edu/search?text=Viktor%20Hamburger>
[76] <http://echo.mpiwg-berlin.mpg.de/ECHOdocuView?mode=imagepath&url=/mpiwg/online/permanent/library/TAQKCW5C/pageimg>
[77] <http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0CCEQF>
[78] <https://embryo.asu.edu/library-congress-subject-headings/gastrulation>
[79] <https://embryo.asu.edu/library-congress-subject-headings/embryos>
[80] <https://embryo.asu.edu/library-congress-subject-headings/embryology>
[81] <https://embryo.asu.edu/library-congress-subject-headings/cells>
[82] <https://embryo.asu.edu/library-congress-subject-headings/tissues>
[83] <https://embryo.asu.edu/library-congress-subject-headings/cell-differentiation>
[84] <https://embryo.asu.edu/library-congress-subject-headings/anatomy>
[85] <https://embryo.asu.edu/library-congress-subject-headings/vertebrates>
[86] <https://embryo.asu.edu/library-congress-subject-headings/invertebrates>
[87] <https://embryo.asu.edu/library-congress-subject-headings/embryological-development>
[88] <https://embryo.asu.edu/library-congress-subject-headings/organs>
[89] <https://embryo.asu.edu/library-congress-subject-headings/organs-anatomy>
[90] <https://embryo.asu.edu/library-congress-subject-headings/pander-christian-heinrich-1794-1865>
[91] <https://embryo.asu.edu/library-congress-subject-headings/rathke-heinrich-1793-1860>
[92] <https://embryo.asu.edu/library-congress-subject-headings/baer-karl-ernst-von-1792-1876-0>
[93] <https://embryo.asu.edu/library-congress-subject-headings/huxley-thomas-henry-1825-1895>
[94] <https://embryo.asu.edu/library-congress-subject-headings/lankester-e-ray-edwin-ray-sir-1847-1929>
[95] <https://embryo.asu.edu/library-congress-subject-headings/haeckel-ernst-1834-1919>
[96] <https://embryo.asu.edu/library-congress-subject-headings/his-wilhelm-1831-1904>
[97] <https://embryo.asu.edu/library-congress-subject-headings/wilson-edmund-b-edmund-beecher-1856-1939>
[98] <https://embryo.asu.edu/library-congress-subject-headings/kolliker-albert-1817-1905>
[99] <https://embryo.asu.edu/library-congress-subject-headings/conklin-edwin-grant-1863-1952>
[100] <https://embryo.asu.edu/library-congress-subject-headings/spemann-hans-1869-1941>
[101] <https://embryo.asu.edu/library-congress-subject-headings/nieuwkoop-pieter-d-pieter-dirk>
[102] <https://embryo.asu.edu/medical-subject-headings/germ-layers>
[103] <https://embryo.asu.edu/medical-subject-headings/endoderm>
[104] <https://embryo.asu.edu/topics/processes>
[105] <https://embryo.asu.edu/formats/articles>