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„Joseph Hyrtl's Embryological Collection: Comparative Anatomy and Evolution"

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Joseph Hyrtl's Embryological Collection: Comparative Anatomy and Evolution

To both my parents.
Thank you for making this possible.

1. Introduction

1.1. Motivational Background

While attending one of many didactics courses at Vienna University I had the lucky chance to peek into the zoological collection. Impressed by the short insights I chose to attend the course “collection sciences and research”. Ao. Univ.-Prof. Dr. Hans Leo Nemeschkal and Assistant Collection Curator Maximilian Petrasko, both teaching at the Department of Theoretical Biology, shared fundamental and technical information in the field of collection sciences and shared historical and contemporary insight concerning management techniques of zoological and even botanical collections. The acquired skills were finally put to test the capability of the students to elaborate different science projects related to collection sciences at the University of Vienna in particular.

Fascinated by the outcome I chose to approach one of the lecturers who shared the opportunity of working on wet specimens produced by famous 19th century comparative anatomist Joseph Hyrtl more than 100 years earlier.[1] Upon first inspecting the collection it became apparent that more than 400 specimens had to be methodologically elaborated and evaluated. This required expansive background research and many hours of study in the dark chambers of the zoological collection.

[1] Many if not most of the specimens held at the zoological collection of Vienna University bear Hyrtl's own signature and catalogue number. A part of the collection does not bear his signature or was contributed by more near-term zoologists such as Franz Spillmann.

As it is well established, not only Joseph Hyrtl managed to reach an awareness for the fact that is evolution. Through his works in comparative anatomy, in particular by comparing certain life forms to one another, he reached an understanding that a godly driven force could not be the reason for the succession of different life forms. According to him, anatomical features where not only based on each other, but were often convergent developments to reach an adaptation to the same or similar niches.[2] As this is one of many approaches to evolution, and since it provides an opportunity to grasp the concept of evolution, a milestone reached by this project is to offer or design an educational tool for high school students or similar third parties to gain insight in evolutionary patterns or to revitalize their understanding on evolution from a different viewpoint, based mainly on both Hyrtl's theoretical work and the specimens he left with Vienna University's zoological collection.

[2] Joseph Hyrtl took many years to reach his understanding of evolution. Detailed information can be obtained in the following chapters.

1.2. Goals

One of the main objectives of this diploma thesis was to explore Joseph Hyrtl’s opinion on evolution. This project, or rather the great foundation Joseph Hyrtl provided, does offer certain advantages. One can only be sure that this Austrian anatomist, as also supposed by Ao. Univ.-Prof. Dr. Hans Leo Nemeschkal, did not only use his specimens for his own entertainment, but that he collected this specimens from all around the globe with the intent to use them in teaching and as educational tools. Enlightened by his feat one of the goals of this thesis is the design of aforementioned educational tool.

As the mindset of Joseph Hyrtl can only be empirically explored by studying his extensive theoretical work, this task was also a big part of this project. Not only do his teachings and proposals offer the potential to grasp the mindsets and perceptions of developmental pathways in animals during his lifetime, but moreover the potential to grasp the historical importance of his oeuvre for our time. The latter did most certainly play a huge role in the understanding of natural selection and evolution not only in Vienna, but also in the far reaches of the Austro-Hungarian Empire and through his several connections to other individuals of the western hemisphere as well.

To put things into a clear perspective, the most important questions of this thesis are:

- How can the progression of Hyrtl's mindset be seen in his theoretical work and how did Hyrtl's understanding of evolutionary patterns emerge over time as brightly illustrated in his several books?
- How did Hyrtl compare to other biologists, anatomists, etc. of or around his lifetime?
- How does his collection, held at Vienna University's Department of Theoretical Biology, reflect his credo and how can this be seen in the specimens and preparations left behind at this institution? To which extent are Hyrtl's ideas on evolutionary patterns reflected in his collection?
- His oeuvre offers the opportunity to design an e-learning tool or application for use in Austrian schools. How can such an extensive concept be compressed into a small tool to be used in education? Which educational standards as offered in the model of competence (Kompetenzmodell) for natural sciences provided by the Austrian Ministry of Education must be met?

Apart from this thesis, arguably one of the most important features of this project was to digitize Hyrtl's collection to be added to an online database. This provides the opportunity for other institutions to access the collection and its specimens. While accessing the collection an inventory was established. It provides pictures from different angles and additional information, partly by evaluating the labels provided by Hyrtl, but moreover also by adding more descriptive data and by trying to determinate undetermined specimens and updating outdated taxonomic determinations to a contemporary status.[3] Joseph Hyrtl's collection does not only hold embryological specimens but also adult specimens, often a vast array of species from the same or related genera, unprepared or showing a huge range of different preparations.

[3] More information on sources for taxonomic updates and/or determinations is shared in the introduction to the related chapter.

Disclaimer

Please be advised that all images in this diploma thesis were taken by the author of this diploma thesis unless stated otherwise. The photographs in this thesis mainly depict specimens of the embryological collection of Joseph Hyrtl, held at the zoological collection of the Department of Theoretical Biology of Vienna University. These images were taken for scientific documentation purposes and to be added to an online inventory or database. Other images carry information regarding the copyright and location at which the object is held in their respective captions. In case of any inadvertent copyright infringement the author of this thesis gently requests consultation by the respective person or institution.

2. Materials and Approach

The basis of this diploma thesis is Joseph Hyrtl's embryological collection. Several hundred specimens are held in the “Feuchtsammlung” (collection of wet specimens). Apart from the “Trockensammlung” (collection of dry specimens) it is one of the most extensive storage facilities for zoological preparations held at the Department of Theoretical Biology at Vienna University. The locality is an enclosed underground compartment which offers thousands of sealed vials and jars filled with alcohol, formalin or similar solutions to store zoological specimens or preparations for the longest possible time.

During the late spring and early summer of 2017 Hyrtl's collection was inspected in detail and pictures were taken from different angles. At the same time an inventory was established and all specimens were categorically and consecutively numbered, described and mostly determined (They had either been determined before or were, to the best of my abilities, determined to family or genus level).[4] To facilitate this process, several online databases, e.g. www.tolweb.org (the Tree of Life Web project) were used.

[4] Due to the destructive effect of the alcohol solution, the time that had elapsed and the impossibility to open the glass containers and inspect each individual specimen without a glass and alcohol barrier, the effort of trying to exactly determine the specimens in different developmental stages often proved to be futile.

Simultaneously, several archives were visited in person to gain more background information on Joseph Hyrtl:

- Österreichisches Staatsarchiv (National Archives of Austria) in Vienna
- Niederösterreichisches Landesarchiv (Lower Austrian State Archives) in Sankt Pölten
- Archiv der österreichischen Akademie der Wissenschaften (Archives of the Austrian Academy of Sciences) in Vienna

Correspondence with other institutions, such as the National Archives of Hungary or the National Archives of the Czech Republic was held. Unfortunately, this effort did not lead to any additional information.[5]

[5] As Joseph Hyrtl left Hungary when he was quite young this was to no surprise. Nonetheless, Ádám Török of the National Archives of Hungary kindly referred me to other institutions and databases.

3. Short Biographical Overview

3.1. Early Life

Joseph Hyrtl was born December 7^{th}, 1810[6] in the Hungarian town of Kismárton (nowadays Eisenstadt and part of the Austrian state of Burgenland) to Jakob Hyrtl sr.[7] and his wife Franziska Theresia. (Gasser 1991, OEAW 1965) Due to a new employment of his father the family moved to Vienna in 1813 (Gasser 1991).

Joseph Hyrtl inherited his father's interest in music and joined the "Wiener Sängerknaben" (Vienna Boys' Choir) at the royal court, which guaranteed him a proper education at the "k. k. Convict". (Gasser 1991, von Wurzbach 1863)

[6] according to a handwritten letter from his brother (von Wurzbach 1863)

[7] Jakob Hyrtl sr. (Oboist to the court orchestra of count Esterházy) was the son of Martin Hirtl (nota bene: the family name is spelled differently. Even Joseph Hyrtl's last name is often spelled as Hirtl or Hirtel in official documents, such as in reports to the "K.K Studien- Hof- Commission", the imperial office for Education, which can be found at the National Archives of Austria) and fathered three other children, Jakob jr. (a well-known copper engraver), Carl and Therese. (Gasser 1991)

3.2. Education in Vienna

After finishing “high school”, Hyrtl decided to study medicine at Vienna University in 1829. (Gasser 1911, OEAW 1965) Through his great interest in anatomy and dissections he quickly caught the attention of Joseph Berres, who employed him as prosector at Vienna University in 1833 (Gasser 1991, Hirsch et al. 1884, OEAW 1965) or 1832 (von Wurzbach 1863). Hyrtl seemed to be quite gifted with his work, as he managed to manufacture an abundance of anatomical preparations which were held at the “Anatomisches Theater”[8] (or *Theatrum anatomicum,* anatomical theater) in Vienna. (Gasser 1991, von Wurzbach 1863) As the young anatomist was quite gifted, and, through the connections Joseph Berres and Joseph Julius Czermak[9] provided to the public, Hyrtl soon began to hold his own lectures at the anatomical theater. His presentations were quite famous and were often attended by 19th century high society (frequent attendants of his demonstrations were, amongst many others, Franz Graf Stadion or Count Felix Schwarzenberg). (Gasser 1991)

As is apparent through Joseph Hyrtl’s editorial practice, e.g. his monography “*Das Arabische und Hebräische in der Anatomie”* (a textbook on Arabic and

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[8] In 1755 the anatomical theatre was built for educational purposes. Joseph Barth (Professor for anatomy at Vienna University from 1773 to 1786) added a “Sezierboden” (section floor or preparation floor), an amphitheater and a library. Berres and Hyrtl changed the descriptive teaching method to a more comparative one. (Czeike 2004)

[9] Joseph Julius Czermak was Professor for physiology (and later) anatomy at Vienna University and dedicated much of his work to the emerging discipline of comparative anatomy. His microscopic studies on blood may have influenced Joseph Hyrtl in his strive for medicine. He managed the anatomical theater alongside Joseph Berres. (OEAW 1965)

Hebrew in the field of anatomy), he was not only proficient in German, English, Latin or French, but in eastern languages as well. His skills in the Latin language above all (and of course his dedication and knowledge in anatomy and physiology) determined his teacher Joseph Berres to consult Hyrtl for his anatomical Atlas "*Anatomie der mikroskopischen Gebilde des menschlichen Körpers",* one of the first Viennese textbooks of its kind. (Gasser 1991)

Figure 1 The anatomical theater of Vienna University in its historic form in 1786 provided a round tribune and a section floor with gates where medical preparations, dissections and autopsies were shown.
(University of Vienna Archives)

It did not take long for Hyrtl to finish his studies. After only six years the young anatomist gained his doctorate in 1835 in Vienna, where he continued his prosectoral work for the next two years and began to conduct his own studies on malformations. (Gasser 1991, OEAW 1965, von Wurzbach 1863)

3.3. Joseph Hyrtl at Prague‘s Charles University

Only two years after his graduation ceremony Joseph Hyrtl settled in Prague (at that time part of the Austro- Hungarian Empire). Here, he was granted professorship of anatomy (Hirsch et al. 1884, OEAW 1965, von Wurzbach 1863) and physiology (Gasser 1991). Hyrtl seemed to be quite pleased with Prague's institutions, his accommodations and especially the colleagues and students that surrounded him, as he told the "medicinisch-chirurgische Directorat" (directorate of the medical and surgical sciences). (Gasser 1991)

The young professor did, however, not stay in Prague for long. After he rejected a position in Prague to substitute for his young colleague Franz Schuh[10] as surgeon, (Gasser 1991) he decided to move to Vienna.

[10] Franz Schuh (1804-1865) was professor of surgery at Vienna University from 1841 onwards. Based on the studies of Karl Rokitansky and Joseph Škoda, Schuh modernized the treatment of blood effusions in thoracic and abdominal cavities and was one of the first surgeons to perform a paracentesis of the pericardial sac in 1840. (von Wurzbach 1876)

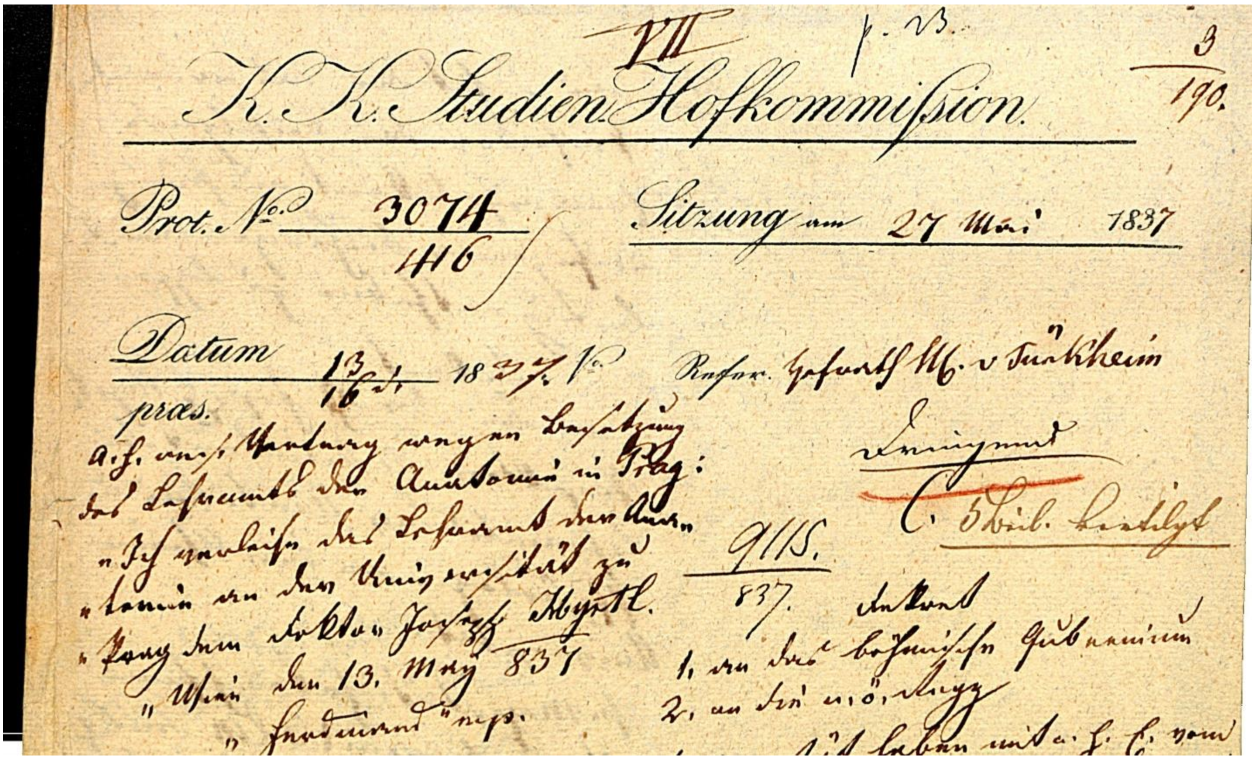

Figure 2 Taken from: „Prot. No. 3074 416 der Sitzung am 27. Mai 1837 an die K.K. Studien Hofkommission“ This image shows the appointment of Joseph Hyrtl as Professor of anatomy at Prague’s Charles University. It reads as follows: […] Vertrag wegen Besetzung des Lehramts der Anatomie in Prag: „Ich verleihe das Lehramt der Anatomie an der Universität zu Prag dem Doktor Joseph Hyrtl, Wien, den 13 Mai (1)837 […] (National Archives of Austria)

[…] Agreement on the appointment for lectureship of Anatomy in Prague: “I bestow the lectureship of anatomy at the University of Prague to doctor Joseph Hyrtl, Vienna, May 13th (1)837 […]

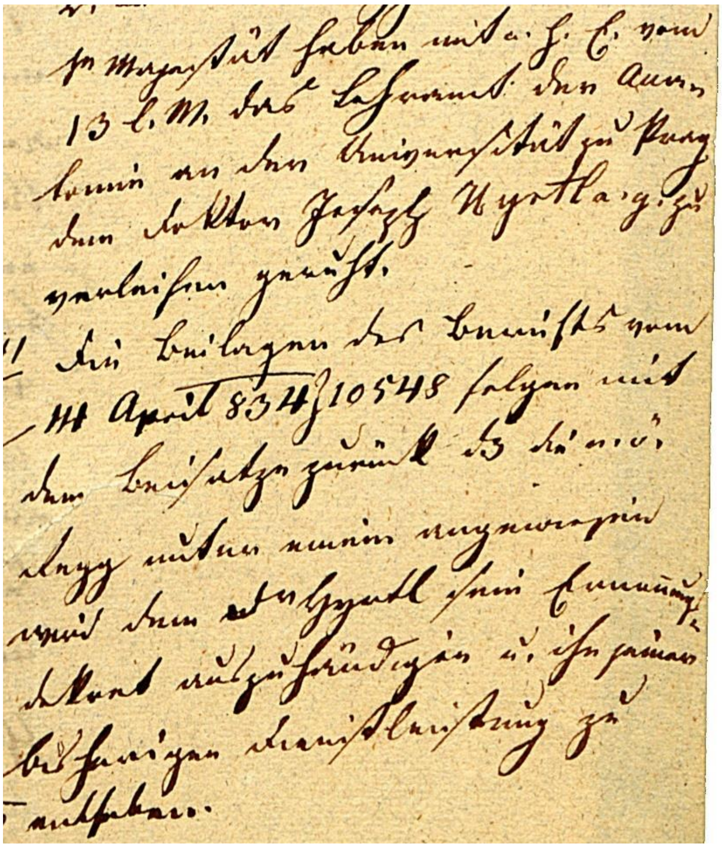

Figure 3 This image is taken from the same page of the protocol depicted above. It reads as follows: […] Mayestät haben mit h.E. (ann.: hoheitlichem Erlass) vom 13 l. M. (ann.: letzten Monats) das Lehramt der Anatomie an der Universität von Prag dem Doktor Joseph Hyrtl a.h. zu verleihen geruht. […] unter neuem angewiesen wird dem Dr. Hyrtl sein Ernennungsdekret auszuhändigen u ihn seiner bisherigen Dienstleistung zu entheben.
(National Archives of Austria)

[…] His majesty deigned to appoint doctor Joseph Hyrtl to the lectureship for anatomy at the University of Prague by royal decree from the 13th of last month. […] therefore, it is ordered to hand over Dr. Hyrtl his decree of vocation and to relieve him of his former duties. […]

3.4. Joseph Hyrtl's return to Vienna

In 1845 Joseph Hyrtl's teacher Joseph Berres died and the former was appointed as his successor. (Gasser 1991) Hyrtl did not seem to enjoy his work in Vienna as he stated himself in 1869. He tried to revolutionize the "Anatomische Anstalt" (department for anatomy) but according to him, "nobody would listen, which encouraged him to dedicate even more time to his preparations and examinations. On the other hand, he seemed to be a quite difficult person to work with, as elaborately explained by Karl Eduard Rothschuh in 1974. According to Rothschuh, Hyrtl invited Ernst Brücke[11] to Vienna in 1849, where Brücke was granted his own "Hundestall" (dog stable) to work on his dogs. However, Hyrtl soon turned on Brücke because of the noise the dogs made, which led to the construction of a new sound-proof stable and ultimately a controversial public dispute between the two of them. (Rothschuh 1974) In his article "Über die Selbststeuerung des Herzens: Ein Beitrag zur Mechanik der Aortenklappen" Hyrtl explains the background of accusations between Hyrtl and Brücke surrounding the scientific debate on the nature of the "self-controlled" left ventricle during the systole cycle. (Hyrtl 1855)

[11] Ernst Brücke was a German physiologist born in Berlin in 1819. In his early years Brücke was a member of the "Berliner physikalische Gesellschaft" (physical society of Berlin) and was engaged with optics and the mechanics behind diffusion. In 1849 Brücke moved to Vienna where he worked on speech sounds, chromatics and the physiology of the eye. (von Wurzbach 1857)

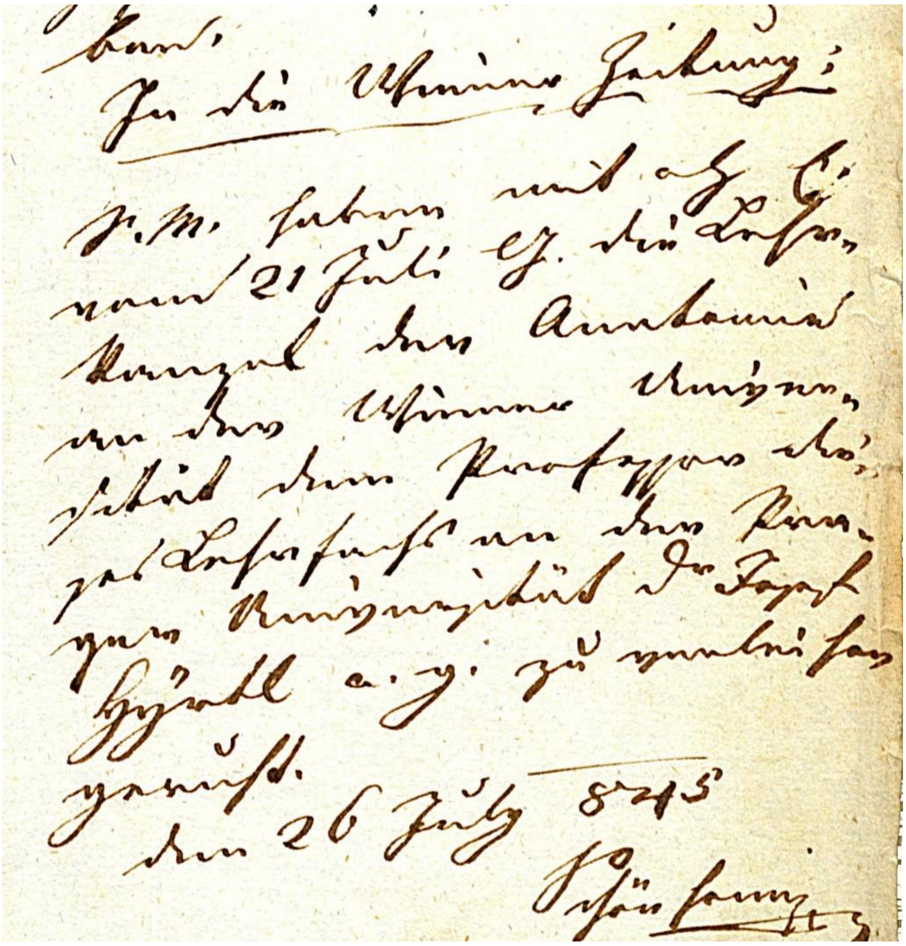

Figure 4 Taken from: „Prot. No. 5220 533 der Sitzung am 2. August 1845 an die K.K Studien Hofkommission “. This quote shows a recommendation of Joseph Hyrtl to be appointed as professor for anatomy at Vienna University and reads as follows: “[…] S. M. (ann.: Seine Majestät) haben mit (ann: ihrem Schreiben?) zum 21 Juli […] die Lehrkanzel der Anatomie an der Wiener Universität dem Professor […] an der Prager Universität Dr Joseph Hyrtl a.h. zu verleihen geruht. Den 26 July -Unterschrift-” (National Archives of Austria)

[…] His majesty has deigned to appoint Dr. Joseph Hyrtl, […] Professor at Prague’s University, for the professorial chair for anatomy at the University of Vienna with his letter from the 21st of July.
The 26th of July -signature- […]

During his time in Vienna, Joseph Hyrtl managed to acquire more than 5000 specimens for his anatomical collections. (Gasser 1991) 1845 was also the year when Hyrtl first managed to cast wax into the respiratory system of *Lepidosiren paradoxa,* which enabled him to successfully determine its status as a fish[12]. (Buklijas 2010) This constituted the base for his undisputed mastership in the field of corrosion anatomy, which also led him to display certain objects at the World Exhibition of 1873. (Buklijas 2010) Interestingly, amongst others, Ziegler's embryological waxes[13] were shown at the same exhibition. (Buklijas 2010, Hopwood 2002)

Being one of the world's most renown Germanophone scientists of the 19th century, Joseph Hyrtl was appointed member of the "kaiserliche Akademie der Wissenschaften" (Royal Academy of Sciences) in May 1847. (Gasser 1991)

During the revolutions of 1848[14] Joseph Hyrtl reached arguably one of the most devastating low points of his academic career. He fled the student protests of Vienna and went to Trieste, where he prepared fish for later examinations. (Gasser 1991) According to the same source, his apartment,

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[12] The dispute around *Lepidosiren paradoxa* is elaborately discussed in the according chapter.

[13] Adolf Ziegler's handmade wax models were used for teaching purposes all around the world and some objects can also be found in the zoological collection of Vienna University. (Harlfinger 2016)

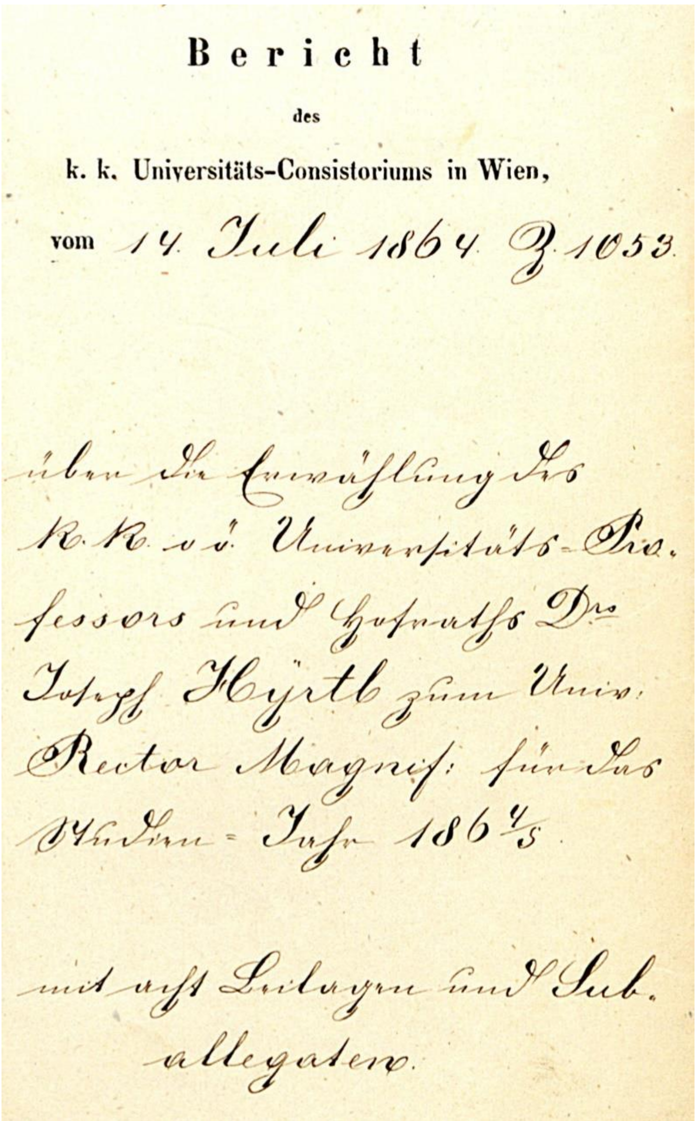
[14] Due to the internal struggles of the Habsburg Empire, the new system of inner and outer politics established by Metternich and amongst many other things the inspiring example of the French revolution of 1848, inspired by a speech of Ludwig Kossuth on the right to vote, students began to march on the Hofburg on the 15th of May 1848. This led to many battles, a short secession of the Hungarians, the resignation of the Emperor and a revival of neo-absolutism in the Austro-Hungarian Empire. (Vocelka 2000)

library and collections were destroyed in his absence. Joseph Hyrtl overcame his urge to emigrate to the United States and started establishing the "Museum für vergleichende Anatomie" (Museum for Comparative Anatomy) in 1850, where he soon reclaimed the objects he had lost during the revolution. (Gasser 1991, von Wurzbach 1863)

Another controversy arose around Hyrtl when he was appointed rector of Vienna University in 1864 and a year later in 1865 during his speech for the 500th anniversary of Vienna University. (Gasser 1991, OEAW 1965) The former speech, in which he debated and challenged materialism and gathered a huge audience[15], was received comparably well. The latter, on the other hand, was received as "an insult to the enlightened Austria". He praised the church-like character of the Viennese University and proclaimed the "domination of science by religion"[16]. (OEAW 1965)

[15] Albeit this fact should be accredited to his fame amongst students.

[16] „Die Herrschaft der Kirche über die Wissenschaft“



Bericht

des

k. k. Universitäts-Consistoriums in Wien,

vom 14. Juli 1864 Z. 1053.

über die Einstellung des k. k. o. ö. Universitäts-Professors und Hofraths Dr. Joseph Hyrtl zum Univ. Rector Magnif: für das Studien-Jahr 1864/5

mit acht Beilagen und Sub. allegaten.

Figure 5 „Bericht des k.k. Universitäts-Consistoriums in Wien, vom 14. Juli 1864 §1053“ […] über die Einstellung des k.k u.ü. Universitäts-Professors und Hofrats Dr. Joseph Hyrtl zum Univ. Rector Magnif: für das Studien=Jahr 1864/5 […] (National Archives of Austria)

[…] Report of the k.k. Univ. Consistorium in Vienna, on the 14th of July 1864, […] on the appointment of Professor and Hofrat[17] Dr. Joseph Hyrtl to Rector for the academic year of 1864/5" […]

[17] Honorary title in Austria

Joseph Hyrtl was appointed Rector of Vienna University on the 14th of July 1864. He held his inaugural speech on the 1st of October 1864 and his anniversary speech on the 2nd of August 1865. (Gasser 1991)
Due to degradation of his eyesight, (OEAW 1965) Joseph Hyrtl held his last lecture on the 17th of March 1874 and retired shortly afterwards[18]. (Gasser 1991, OEAW 1965)

During the last 20 years of his life Joseph Hyrtl moved to his summer home in Perchtoldsdorf, Lower Austria and continued his studies in private. He had acquired wealth and established an orphanage foundation[19] in Mödling, the expansion of the local hospital and supported the beautification of townscape appearances. (Gasser 1991) He also provided the University of Vienna with 40.000 gulden to enable four students of accordingly poor background each year to study medicine. (OEAW 1965)

[18] According to Rudolf-Josef Gasser, Joseph Hyrtl retired at the age of 63 without statement of reasons. "He had lived amongst corpses for forty years and wanted to spend the short time left alone."

[19] The „Josef Hyrtl – Waisenstiftung" was established in 1888 or 1890 and is now in the hands of the provincial government of Lower Austria. In 2015 the foundation still held more than € 1.5 million and provided for more than 100 children. (NÖ LRH 2006)

4. Concepts in Hyrtl's Monographies

4.1. Lepidosiren paradoxa

The South American Lungfish, or *Lepidosiren paradoxa*, was first found in Brazil and described by the Austrian Zoologist Johann Natterer[20] who characterized it as being amphibious, and put it in the "family of Detrotremata" and in the "division of Dipnoa", thus already acknowledging the capability of the lungfish to breathe. (Leuckart 1840)

According to Leuckart, who presented Natterer's theories on this species at the "Versammlung der Deutschen Naturforscher" (Assembly of German natural scientists) in Freiburg, where a debate arose on how to taxonomically characterize this species. While some of the attendants speculated that *Lepidosiren paradoxa* had to be a fish, many others believed it to be an amphibian, mainly because the nasal openings lead to the pharyngeal cavity, as is the case with *Siren sp.* and *Proteus anguinus*. Even the National Museum of Natural History in France agreed with the latter approach, stating that it had to be a close relative of salamanders. (Leuckart 1840) On the other Hand, Leuckart acknowledges that Owen, who described the first African lungfish, allocated the genus to the fishes and states that it had to be a link between Sarcopterygii and (ann: the now obsolete class of fish) Malacopterygii. Surprisingly, for a short while, even the possibility of

[20] Joseph Natterer was the son of a "kaiserlicher Falconier" (imperial falconer) and learned taxidermy and different preparations on animals in his youth. Natterers biggest expedition led him to Brazil in 1817 where he stayed for 22 years. During his time in Brazil Natterer discovered hundreds of birds, gathered about 40 000 different animal specimens and 2000 "ethnological objects". (Schifter 1992)

Lepidosiren being reptilian (however without any given explanation) was mentioned. (Günther 1872) According to Albert Günther, before the discovery of the lungfish, the classification was quite simple. Fish had gills, while reptiles had lungs. Since some of these “reptiles” both had lungs and gills (ann: considering the metamorphosis in amphibians), these classifications seemed insufficient and amphibians were added.

In 1845 Joseph Hyrtl published his book on this prevailing discussion. In the same year he had obtained a female specimen of *Lepidosiren paradoxa*, one of the first of its kind since the return of Natterer to Europe. After explaining the constitution of his specimen in detail and disproving assumptions made by others, he concludes that *Lepidosiren* is not closely related to any other fish species. He clearly states that after the collapse of the pre-world, all connections to the creation seem to have been cut.

> “Mit dem Untergange der vorweltlichen Generation sind – so vermuthe ich – auch die Bindungsglieder grösstentheils verschwunden, welche dieses Thier an die jetzige Schöpfung knüpfen[…]“

Hyrtl debunks the myth surrounding the classification of fish and reptilian and states how lungs and gills do not, but the “organ of smell” do constitute distinction criteria. (Hyrtl 1845) According to Hyrtl other fish have lungs, or at least elementary “breathing sacks”, as they can be seen in Siluroidae and eels. In his further elaborations Joseph Hyrtl explains the difference in character between the air bladder and lungs, and how the vascular system surrounding the tissue in question indicates its classification. Seemingly, Hyrtl was well aware of the connection between air bladders and lungs in fish.[21] He explains how some of his colleagues, e.g. “Valentin” had examined air bladders of different fish but did not provide additional information on the constitution the respective vascular systems. (Hyrtl 1845) Therefore, according to Hyrtl, it was not possible to determine whether the examined organ had to be classified as a respiratory organ or as lungs. (Hyrtl 1845)

Following his conclusions on the lungs, Joseph Hyrtl gives the same explanation on other hot-button issues, such as the vascular system of the aortic arch or the position of the bladder regarding urogenital opening. Accordingly, his colleagues argued on the nature of *Lepidosiren* by showcasing distinctive traits of amphibians and fish. (Hyrtl 1845) In some cases, Hyrtl refers to distinctive traits of one class, which can be found in some species of the other class.[22] In other cases, as in the position of the bladder regarding to the aforementioned opening, he explains how some traits cannot be considered as “exceptions to the rule”. (Hyrtl 1845) In the same book, the Austrian anatomist examined that in *Lepidosiren*, the position of the bladder is above the rectum, and the urogenital opening is embedded behind the anus. Hence, this species shows a distinctive fish trait.

[21] By comparing the color of blood in afferent and efferent blood vessels and the constitution of their connection to the heart he concludes how to characterize the organ. He is seemingly aware that there must be some sort of connection between the two from an evolutionary viewpoint, albeit he never clearly says so.

[22] This again shows how Joseph Hyrtl is already aware of an evolutionary pattern, since he mentions how some traits can be found in primal species of the more recent class and therefore can be considered exceptions to the rule. The apparent connection between related species, families and classes must therefore already (at that point) have been apparent to him.

In *Amphioxus lanceolatus*,[23] another debated species on the other hand, the position of the opening in front of the anus and the lower fins cannot be considered as exceptional traits since the relevance cannot be construed considering the lack of knowledge regarding the nature of the ureter and genitalia. (Hyrtl 1845)

To determine the nature of this fish more specifically, Hyrtl also gives hints to the embryonic development of amphibians. Since some colleagues hinted that in *Lepidosiren paradoxa* afferent vessels ended in the heart and not the aorta, as is the case in amphibians, Hyrtl explains how embryonical stages of *Salamandra atra* exhibit fish patterns. The two separated atria on the other hand must be as unique to the South American lungfish as their lungs are, and clearly constitute a connected trait. (Hyrtl 1845)

The clearest distinction, according to Hyrtl, can be seen in bony structures. *Lepidosiren paradoxa* clearly bares an ichthyic spine and therefore combines fish traits and amphibian traits. As much as Ichthyosaurus and Plesiosaurus can be considered fish due to some traits, *Lepidosiren paradoxa* can be considered amphibian. (Hyrtl 1845)

[23] Today classified as: *Branchiostoma lanceolatum* *(http://www.marinespecies.org/aphia.php?p=taxdetails&id=104906, last visited: 12.3.2018)*

Joseph Hyrtl ends his conclusions by comparing his explanations and findings to the African lungfish[24] and how he can relate to the doubts of these two species being in the same genus. Nonetheless Hyrtl believed them to be in the same genus and proposed the (back then) new family of Pneomonichthyi or Pulmonati.[25] (Hyrtl 1845)

[24] Presently, the African Lungfish is classified as *Protopterus annectens*. The species is part of the Family of Protopteridae, which, together with the Family of Lepidosirenidae constitutes the order of Lepidosireniformes. (http://www.iucnredlist.org/details/169408/0, last visited: 12.3.2018)

[25] Although Joseph Hyrtl proposed his own classification, Hyrtl states that he preferred Müllers classification "Sirenoidei", since this name not only refers to the "inner trait". Müller had already classified *Lepidosiren paradoxa* as a fish species two years prior to Joseph Hyrtl, albeit based on less data. (Hyrtl 1845)

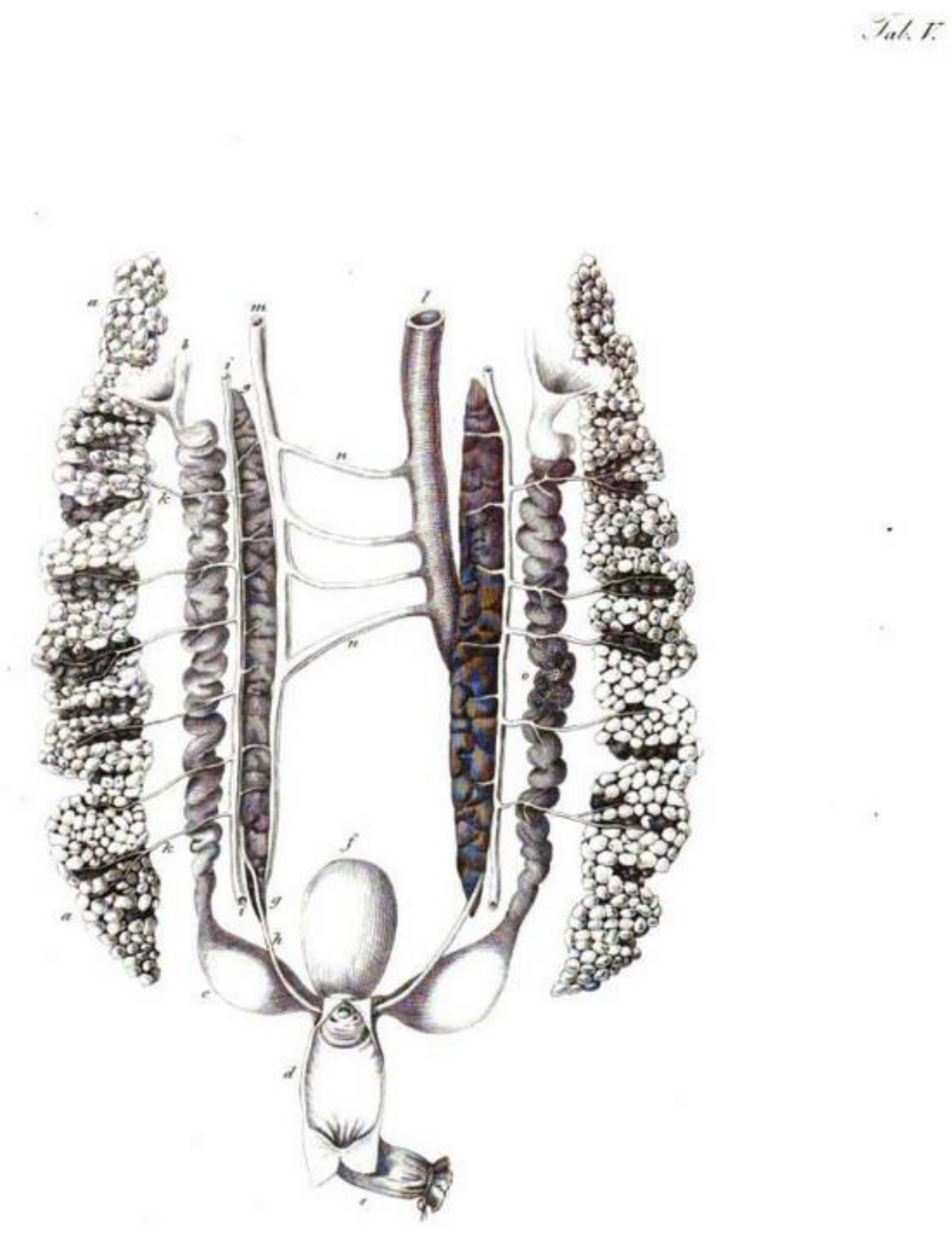


Figure 6 Copper engraving by Joseph Hyrtl depicting ureter and reproductive organs as seen from the spine in Lepidosiren paradoxa. a. ovaries, b. ventral opening of oviduct, c. extension of oviduct, d. cloaca, f. bladder, g. kidneys, h. urethra, i. afferent blood vessels of kidneys, l. right V. cava, m. (smaller) left V. cava, n. four connecting vessels of V. cavae Image from Joseph Hyrtl's Lepidosiren paradoxa (Hyrtl 1845, p. 70)

4.2. Hearing in Mammalia

Joseph Hyrtl compared hearing in Mammalia in different stages and bases his framework on earlier works done by Huschke and Soemmering, who, according to him, did such excellent work in anatomical explanations and comparison work, that he did often not deem it necessary to add additional profound explanations. (Hyrtl 1845)

Soemmering (1755-1830) was well known for his depictions of early human development. The main source of German anatomist Samuel Thomas Soemmering’s work were embryos from induced and spontaneous abortions and his preparations and drawings were often considered to be the best of that time, which comes to no surprise as he often selected his preparations to meet his demands in beauty and perfection. (Hopwood 2015) According to Hopwood this highlighting in aesthetics did however not “appreciate” the criteria appropriate of age and thus, “judged by adult standards”, other scientists in the 1830ies regarded Soemmering’s drawings and depictions as abnormal and cut-off from “direct observation”. Therefore, investigations of other species (ann: as is the case in Joseph Hyrtl’s comparative work on hearing) seemed to yield more insight, “even about the first genesis of the human embryo”. (Hopwood 2015)

In his "Vergleichend-anatomische Untersuchungen über das Innere Gehörorgan des Menschen und der Säugethiere" Joseph Hyrtl compares the structure of the human ear – the ossicles, the inner ear and the tympanic cavity – to other mammals.[26]

Arteria stapedia is a small branch of Arteria carotis interna and is the main source of cranial blood supply in Lemuriformes. In Haplorhini however, A. carotis interna remains an embryonical or vestigial trait, while A. promontorii assumes the main role in cranial blood supply. (Geissmann 2003) Joseph Hyrtl was quite aware of the importance of A. stapedia.[27] As he states, this small vessel could easily be overlooked, if it was not for its "animal-like" appearance. (Hyrtl 1845)

[26] As he states himself, Joseph Hyrtl spends several years collecting and asking colleagues for different animal skulls to perform his examinations, which was quite costly as the examination of the inner ear meant the destruction of those valuable and rare specimens. (Hyrtl 1845) This too reveals that Hyrtl had associations all over Europe, which enabled him to restore his prized collection rather quickly after the revolution of 1848.

[27] As he does not specifically refer to these vessels by their scientific terms but rather refers to them as (e.g.) "Arteria of the stapes", it is not obvious if he refers to A. stapedia explicitly, or rather to any similar blood vessels in this region which assume A. stapedia's role in other primates.

Joseph Hyrtl also compares similar structures of the ear in different species and shows his awareness of adaptational processes in animals. In one case Hyrtl compares the similar structure of afore-mentioned Arteria carota in *Meles sp.* and *Ursus sp.* and concludes that, since both animals hibernate, this must be an adaptation to environmental conditions. (Hyrtl 1845)

The most remarkable part of Joseph Hyrtl's anatomical examinations of hearing in mammals comes with his comparative work on humans and closely related primates. Certain "aberrations" in ossicles of either adults or embryos of humans lead Hyrtl to compare these abnormalities to structures in *Pan sp.* and *Pongo sp.* Such is the case in a cavity near the semicircular canals, which is quite pronounced in most mammals, but exists only during early stages of human development, and interestingly, only in young chimpanzees and orangutans. (Hyrtl 1845) In post-natal humans and in aged chimpanzees and Orangutans, only a fissure remains according to Hyrtl. Accordingly, as he puts his discoveries in primates in contrast to the lack of this fissure in other mammals, Hyrtl must have already been aware of certain adaptational and evolutionary patterns at that stage of his life.

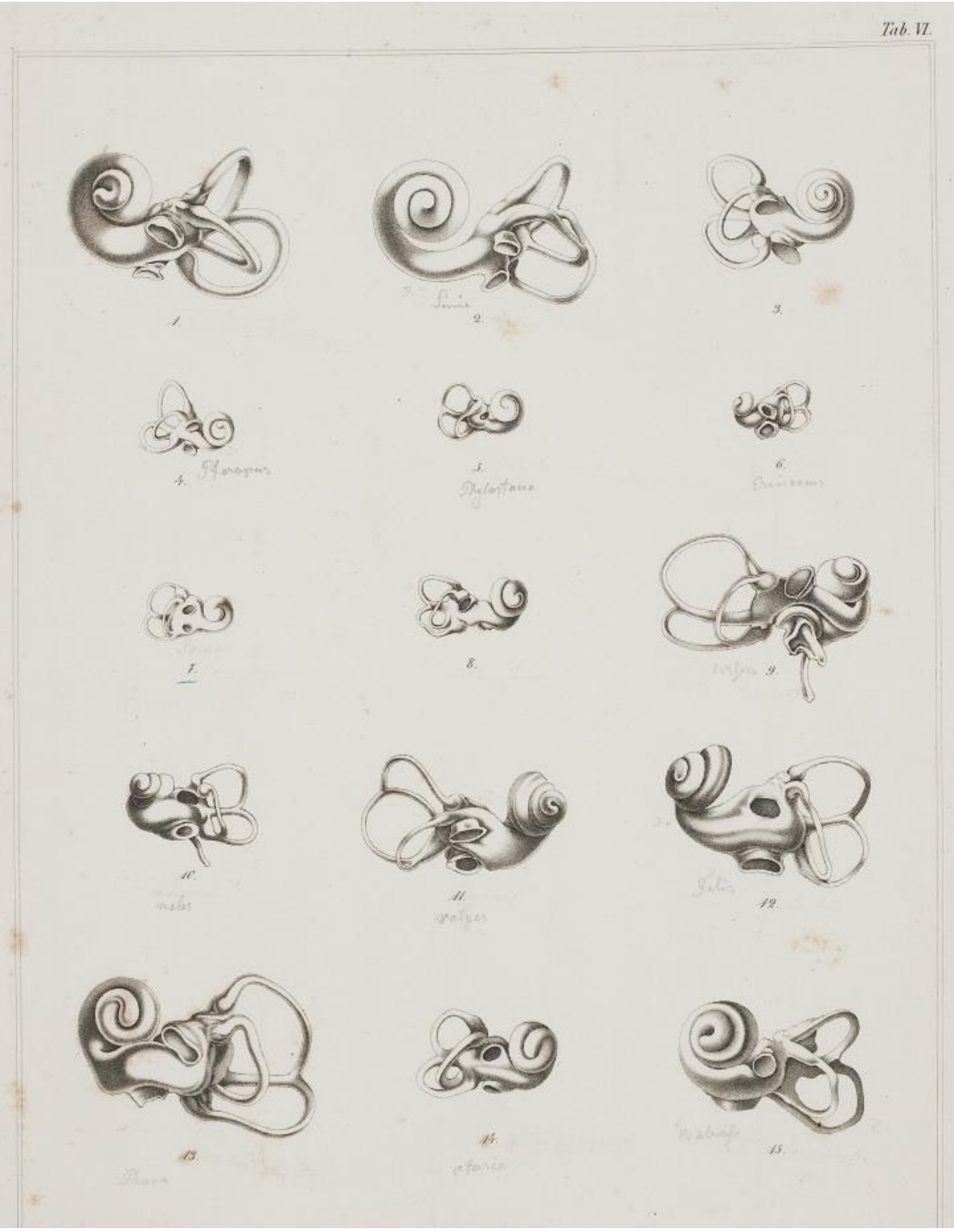


Figure 7 Image shows (in some cases) vastly different acoustic labyrinth in mammals. 1. labyrinth in newborn child, 2. labyrinth in "Cynocephalus sphinx" (Papio cynocephalus, Yellow baboon). The first two structures are clearly quite similar. Image from Joseph Hyrtl's "Vergleichend-anatomische Untersuchungen über das Innere Gehörorgan des Menschen und der Säugethiere" (Hyrtl 1845, p. 146)

4.3. Human Anatomy

In 1846 Joseph Hyrtl published his great anatomical teaching book and for the first time explained his thoughts on evolution and the origin of life in detail. Herein he explained that common sense dictates physics to be the science of inorganic matter, while biology or physiology had to be the science of organic matter. Life, according to him, was only a consequence of a row of activities from birth to death, as experienced by an organic body, while both organic and inorganic bodies underlay the laws of nature. Therefore, while inorganic "bodies" where mainly "mechanical combinations of binary nature, organic bodies were composed of tertiary and quaternary chemical bonds".[28] He goes on to explain that because organic bonds were much harder to break, there had to be an "organic force" ("organische Kraft"), which "opposed physical and chemical laws". Joseph Hyrtl considered this "force" to be the result of a perpetual cycle of bonds breaking up and forming new substances.[29] (Hyrtl 1846)

[28] Joseph Hyrtl was seemingly not aware of the role of carbon in organic chemistry.

[29] "Dieses Agens nun, welches die Verbindungsverhältnisse der Grundstoffe im organischen Körper erzwingt, und für eine gewisse Zeit aufrecht erhält, […] kann als organische Kraft, den chemischen oder physikalischen Kräften entgegengesetzt werden, wobei jedoch zu bemerken ist, dass das Wort Kraft immer nur die gedachte, nicht die wirkliche Ursache von Erscheinungen bezeichnet. Die organische Kraft beschränkt ihre Thätigkeit nicht blos auf das Resultat des ruhigen Nebeneinanderseins der neuen Verbindungen, Jeder Bestandtheil eines organischen Körpers ist, so lange das Leben dauert, in einem ununterbrochenen Wechsel seiner Stoffe begriffen." (Hyrtl 1846)

Hyrtl gives the example of blood. During its lifetime an organism takes in iron. However, Hyrtl assumes, each iron molecule changes its physical properties as it could otherwise be separated from blood by use of magnets. Nonetheless, the same amount of iron said organism took in during its life is left behind after the decomposition of the body. (Hyrtl 1846) This cycle of "absorption, processing, consumption and substitution" was considered to be metabolism by Hyrtl – a phenomenon inorganic matter did not show. According to him, inorganic bodies could change their appearance, but once formed, the molecules this body was composed of, never changed. (Hyrtl 1846) All these explanations clearly show that while Hyrtl did not exactly name this phenomenon of perpetual change and process, he clearly was aware of some sort of rudimentary understanding of a carbon cycle.

This textbook has to be considered a great source on his understanding of a "genetic plan", which drives the formation and activity of each living organism. A "native plan" ("eingeborener Plan") was the source of information and the cause of "irrefutable laws" for each organic body.[30] As it is the case with a machine, from the first moment to its last, this plan coordinated the aforementioned "organic force", or this cycle of life, without interruption.[31] Finally, after life had expired, all organic components were returned to their inorganic state. (Hyrtl 1846) Joseph Hyrtl considered his

[30] „Nach einem ihr eingeborenen Plane entwickelt die organische Kraft den Organismus, entborgt der Aussenwelt den Stoff, aus welchem sie ihn aufbaut, und giebt ihr denselben verändert wieder zurück. […] Von der ersten Bildung des organischen Keimes bis zu jenem Momente, wo das Lebendige den unabwendbaren Gesetzen der Auflösung anheimfällt, wirkt sie ohne Unterbrechung.“ (Hyrtl 1846)

[31] Joseph Hyrtl considered interruption of this genetic plan to be the death of the organism. (Hyrtl 1846)

organic force to be the explanation of each life form, while also explaining that future research and “insight” into the body would clarify his hypothesis. Joseph Hyrtl’s theories quite apparently indicate his assumptions of something similar to a genetic code and hereditary traits or information.

“Diese Ideen sind in unserer Zeit so kühn und grossartig hervorgetreten dass sie selbst die Macht geltend machen, die Kluft zu ebnen, welche den Menschen von der Thierwelt trennt, und seinen Ursprung, seine höhere Organisation und geistige Begabung, nur als gesetzmässige und unabweisliche Folge von Entwicklungen angesehen wissen wollen, welche in die entlegenste Ferne der Geschichte der Erde und ihres organischen Lebens zurückreichen. Diese Entwicklungsfolge soll es verstehen lehren, dass der Mensch nicht geschaffen wurde, sondern durch zwingende Macht der Naturgesetze entstand, d.h. sich aus niedrigeren Wesen, als es selbst ist, allmälig zu dem entwickelte, was er jetzt ist.“ (Hyrtl 1846)

“These ideas have emerged so boldly and magnificently in our time, that they themselves enforced the power to smoothen the gap that separates mankind and animals. Its (ann: mankind’s) origin, organization and mental capabilities can therefore only be seen as legitimate, unrefusable developmental sequences, which reach back to the ancient history of earth and organic life. These developmental sequences signify, that man was not created, but developed by the binding force of natural law. In other words, mankind gradually evolved from lower lifeforms to its present state.”

In bold contrast to the speeches he gave at Vienna University, Joseph Hyrtl proposed quite different ideas in his anatomical textbook. While praising the domination of religion in his speech in 1865[32], Hyrtl refuses creationist thought in this anatomical textbook. The driving force behind this epiphany seems to be the field of comparative anatomy. While zootomy, anatomy and topographic anatomy in particular only describe certain lifeforms,

[32] See chapter 4.4. Joseph Hyrtl’s return to Vienna for more information.

comparative anatomy compares said lifeforms and puts them into contrast. Comparative anatomy therefore shows how life developed itself from basic lifeforms. (Hyrtl 1846)

“Die Entwicklungsgeschichte oder Evolutionslehre beschäftigt sich nicht mit dem, was die Organe des thierischen Leibes sind, sondern wie sie es wurden.“ (Hyrtl 1846)

“The developmental history or theory of evolution is not concerned with what the organs of animally bodies are, but how they became.” These phrases clearly constitute, or rather represent the core or first reference point of this diploma thesis. Joseph Hyrtl clearly states that these “ideas” were already apparent during his lifetime. Nonetheless he states that the principle of evolution was unalterable, and that one could only conclude that a natural “force” or “law” was the fundamental mechanism behind the origin and development of life, rather than an omnipotent entity. Astonishingly, he published this short introduction to evolution merely as anecdotes to his great anatomical textbook, quite in contrast to Charles Darwin, who elaborately explains his thoughts on this principle on more than 500 pages. Still, Darwin’s “On the origin of species”, which was published in 1859, remains a widely perceived foundation to evolutional theories.

Incidentally, Joseph Hyrtl and Charles Darwin reached the same understanding in taking quite different paths. The former reached his understanding through comparative anatomy as explained in this thesis. The latter, on the other hand, examined the mechanism of selection. In the first chapters of his book he explains how man-driven selection and breeding changed the appearance of domesticated animals (e.g. pigeons) and crops. These were the exact mechanisms he saw in different species while travelling onboard the HMS Beagle for several years – he therefore concluded that these adaptational mechanisms and natural selection point towards evolution as the origin of life. (Darwin 1859) In the same manner, the mechanics and principles of evolution can be grasped from several more perspectives.

4.4. Hyrtl's monstra

Hyrtl was also quite concerned with developmental abnormalities. Especially in sexual organs he assumed that "androgynae" or "gynandri" were left behind in earlier developmental stages. (Hyrtl 1846)

On another note, Joseph Hyrtl explains the importance of the development of nasal cavities for the formation of two separate eyes. He had observed that specimens of different species show a "cyclops-like appearance" if said cavity had not formed during embryonic development. These one-eyed specimens often show an "elephant-like" trunk (which he considered remnants of a nose) above their single eye, which is embedded in a conjoined single cavity. (Hyrtl 1846) Plinius the elder already mentions abnormal newborns. Besides a newborn child in Saguntum which went "straight back into the womb", Plinius also mentions "a pig born with human hands and feet", or a woman which gave birth to a snake. (Knox, McKneown 2013) Joseph Hyrtl mentions these "stories"[33] too. He explains that medieval justice considered these women acquaintances "of Satan" and burnt mothers with similar delivery. (Hyrtl 1846)

[33] Seemingly, Joseph Hyrtl had another interpretation to these stories. While he did not mention the newborn child of Saguntum who fled Hannibal's invasion straight back into its mother's womb. The pig-like newborn was apparently showing the "elephant-like trunk" he mentioned earlier.

There are also other occasions where Joseph Hyrtl mentions his cyclopes. In his “Handbuch der topographischen Anatomie”, another textbook for anatomy, Joseph Hyrtl refers to said cases as “monstra”. Specimens missing both orbital cavities were extremely rare and often still showed a “dent” between the joined frontal bone and upper jaw. (Hyrtl 1871) Instances with newborn children having a single eye, on the other hand, could be observed frequently. In these cases, as he explained in his other anatomical textbook, the ethmoid bone was missing which led the eye sockets to merge and the manifestation of aforementioned “trunk” or “snout”. (Hyrtl 1871) Another peculiarity of these cases is the eye, which he described as being clearly the result of two separate eyes merging together and often showing some degree of exophthalmos. (Hyrtl 1871)

Cyclopia or alobar holoprosencephaly, a lethal defect with unknown cause, results from failure of division of the prosencephalon into a right and left hemisphere during the 18^{th} and 28^{th} day of gestation. (Al-abdallah et al., 2015)

4.5. Corrosion Anatomy

In 1873, shortly before his retirement and after publishing his guidelines on dissections in 1860 ("Handbuch der Zergliederungskunst") Joseph Hyrtl published his guidebook on injection preparations "Die Corrosions-Anatomie und ihre Ergebnisse" (Corrosion anatomy and its outcomes). Herein the Austrian professor states how corrosion casts were unappreciated in his time and how he dedicated himself to this field.

Prior to Joseph Hyrtl, in 17th century Amsterdam, Leyden and Utrecht Dutch anatomists were among the first to perform vascular injections with wax, while the first anatomist to combine wax injections with the corrosion of surrounding tissues was clearly Friedrich Ruysch. (Hyrtl 1846) According to Hyrtl, Ruysch's preparations were however quite brittle as he used mineral acids to corrode the surrounding tissues, and therefore not quite suitable. First verified vascular injections were already made in 15th and 16th century Italy by Leonardo da Vinci, who as well as Bartolomeo Eustachio, used liquids such as ink, gamboge and indigo solutions and milk (for clotting). (Schultka, Göbbel 2003)

Joseph Hyrtl's recipe for the ideal injection mass proves to be quite complicated to reproduce and involves many steps. For his preparations he used no fat but mastic resin, "Jungfernwachs" (ann: unaltered fresh and newly produced beeswax) and specific components for coloration (e.g. cobalt or ultramarine for blue). (Hyrtl 1846) After injecting the blood vessels with this mass, Hyrtl embedded his specimens in concentrated hydrochloric acid between two to ten days according to size and later rinsed this concoction by filling his mouth with water and squirting it on the surface of the specimen through a glass tube by adjusting the pressure with his cheeks. (Hyrtl 1846) Subsequently Hyrtl used to emerge his casts in water to rinse any acid residues and wrap his corrosion casts in bladders of *Huso huso* (European sturgeon) for stability and longevity. (Hyrtl 1846) This tedious process was quite hard to reproduce for others. His description seemed unsatisfactory in that following Hyrtl's instructions provided a mass that did not yield "even moderately successful permanent corrosions". (Huntington 1897)

Hyrtl's corrosion anatomy was part of what enabled him to solve the riddle of *Lepidosiren paradoxa* and to produce many specimens which were considered a major teaching tool for students and visitors to Vienna University. (Buklijas 2015) It seemed he produced these casts in great quantity as he managed to sell his brittle but instructive teaching aides to many anatomical institutions across Europe. (Teschler-Nicola, Grupe 2012)

5. Other perceptions of evolution

As mentioned before, Joseph Hyrtl was not the only 19th century biologist who discovered evolution. Ernst Haeckel (1834-1919) was a big propagator of Darwin's theory of evolution in Germany. Most known for his principle that ontogeny recapitulates phylogeny (ann: a fact Hyrtl also explains in his "Lehrbuch der Anatomie"), Haeckel was in extensive contact with Darwin, who was convinced that Haeckel was one of the few biologists who understood the concept of natural selection. (Richards 2008) Ernst Haeckel went on to publish his "Natürliche Schöpfungsgeschichte" (The History of natural Creation) in 1868, which was considered by some as a primary source for understanding Darwinism, and his textbooks on radiolarians or medusae amongst others "still remain standard references today". (Richards 2008)

Haeckel was a figure that inspired the Austrian evolutionist Berthold Hatschek (1854-1941) to research the development of the nervous system in Lepidoptera, which enabled Hatschek to draw conclusions on the evolutionary relationship between arthropods and annelids. (Nyhart 1995) While some parts of Haeckel's theory of evolution were widely criticized and modified, other aspects remained unaltered, as is the case in Hatschek's textbook of zoology, which "follows Haeckel in all its main features". (Nyhart 1995) Not only through his examinations on butterflies, Hatschek was quite convinced that "morphology in its narrower sense meant genealogical morphology" - a discipline that tries to establish a relationship between the different life forms. (Nyhart 1995)

Carl von Rokitansky (1804-1878) was a pathological anatomist at the Vienna hospital morgue, who was convinced of a “will to live that resists decay” and thought of this will as a form of aggression. (Fullinwider 2004) In conclusion, Rokitansky considered every activity as assimilation or incorporation, meaning every activity strives towards the incorporation of organic matter and thus propagation. (Fullinwider 2004) On the other hand, according to Rokitansky, the “environment resists” this animalistic urge in every animal, which accordingly develops to adjust to this threat. (Fullinwider 2004)

Karl Ernst von Baer (1792-1876) was another Germanophone physician and zoologist. One of the most interesting proposals of von Baer’s law of individual development was his third proposition, which states that “embryos of different species progressively diverge from one another during ontogeny”, (Brauckmann 2012) a progress, as mentioned before, observed by Hatschek, Hyrtl and Haeckel too. According to von Baer, anyone who studied embryology was aware of the teleological developments during embryogenesis, which only reflect phylogenesis. (Nyhart 1995)

Clearly, there are many more 19th century role models for evolution – even in Germanophone countries. The sole purpose of this short overview is to support Joseph Hyrtl’s proposition that the awareness of evolution was, even during his lifetime and before Darwin’s theories gained wide support, already an apparent fact among established scientists.

6. The embryological collection

6.1. Introduction

In late spring and early summer of 2017 Hyrtl's embryological collection held at the "Feuchtsammlung" was evaluated and digitized. Although not all specimens were produced by Joseph Hyrtl,[34] there are 446 glass containers held at the zoological collection of Vienna University, some containing more than one specimen. Many of these specimens are not of foetal or embryological nature but rather show adults or adult organs.

6.2. Assigning metadata

One of the many goals of this thesis was to achieve a standardized outreach of the embryological collection and in further consequence the zoological collection of Vienna University in general. The purpose of this outreach is to attain a certain level of intra- and interdisciplinary exchange by maintaining easier access to the collection through establishing a database.[35] To achieve this standard, each glass container had to be linked to corresponding metadata, such as the collection number,[36] outdated and current scientific names, the location inside the collection, the specimen's provenance, the

[34] To most specimens a tag was added which serves not only as a source of origin.

[35] Eventually, sharing data and collaboration with initiatives such as the Integrated Digitized Biocollections (iDigBio, www.idigbio.org, last visited: 20.4.2018) is considered desirable.

[36] If the label did not contain according numeration or was missing, a preliminary number was assigned.

determinator, additional information,[37] conditional information of vessels and labels and information on administered preparations.

Digitization of collections is of great importance as they serve as primary sources and historical records for original distribution of specimens, invasive species, conservation issues, diseases, climate change and related scientific questions. (Vollmar et al. 2010) An important norm for assigning metadata is the Dublin Core Metadata Initiative (DCMI) founded in the 1990ies. With an interdisciplinary focus, the DCMI established semantic and syntax recommendations for curation and digitization, as well as guidelines for interoperability which provided a guideline in assigning metadata for this thesis. (Weibel 2000, DCMI 2007/2009, http://dublincore.org/, last visited: 25.4.2018)

To establish a constant quality of output, a digitization workflow is of essence. A practicable workflow in chronological order consists (ann: as mentioned earlier) of five task clusters: evaluation before digitization, image capture, evaluation of specimens and additional data, retaining the correlating label data and adding geodata. (Nelson et al. 2012)

[37] As conceived from the labels and descriptions of content through evaluation

6.3. Technical Equipment

The pictures were taken inside the “Trockensammlung”, a sealed room without any natural daylight. To elevate the specimens a table with white veneer was used, while white background was provided in form of a white screen.[38] To illuminate the objects, spotlights were positioned exactly laterally to the objects in a 45-degree inclination from above and a distance of approximately one meter.[39]

The pictures were taken with a Panasonic Lumix FZ 48 digital camera. In most cases a picture of the label, an overview picture, two lateral views and, if required, close-ups of relevant preparations were captured. All information was stored in an excel spreadsheet.

[38] Prior to evaluation, different background colorations were tested but seemed too contrastive. Similarly, a turntable was perceived impractical as exact rotation did not deem necessary.

[39] Lateral positioning is highly recommended, as other placements always correlates with reflection on the glass surface or dazzling. The inclination can be changed according to glass container dimensions, although 45 degrees often seem most adequate.

6.4. Monstra

Figure 8 Embryo of Bos taurus

Above specimen (no. p038) shows an embryo of *Bos taurus.* As explained in chapter 4.4., this specimen shows all symptoms of cyclopia. Due to the missing ethmoid bone, both eyes and orbital cavities have joined. The enlarged eye is protruding and a trunk-like structure without bony tissue is clearly visible above the single eye.

Figure 9 Embryo or newborn Sus scrofa

Another specimen showing symptoms of cyclopia. This juvenile *Sus scrofa* has no protruding eye (no. p060) but the eyelids seem deformed and skewed. The trunk-like appendix can again be seen above the eye with seemingly missing bones.

Figure 10 Embryo of Delphinapterus leucas cf.

This specimen (no. p056) was determined as a member of “Delphinapteri” by its identifier. Though missing the trunk-like appendix (ann.: maybe because of the different nose structure in Cetacea), a conjoined and closed single eye is clearly visible in the middle of the forehead.

6.4.1. Other "monstrosities"

In his "Lehrbuch der Anatomie" Hyrtl explains how evolution "studies the law" of how simple germs develop into adults, how organs are formed and the metamorphoses they "run through". All deviations to this law are considered "disturbances in development" and "monstrosities". (Hyrtl 1846)

Figure 11 Embryo or newborn Sus scrofa

Specimens no. p068 of Hyrtl's collection are conjoined twins featuring a shared head and partly shared thorax but two lower bodies with two sets of legs.

Figure 12 Several specimens of Felis catus dom. and one specimen of Sciurus vulgaris

In jar no. p137 three juvenile cats and a squirrel can be seen. The conjoined twins to the left share head, thorax and abdomen, but show two arguably separate hips and four hind legs. One brown tail and two feet are visible in the lower left corner, the other lower body is bent to the specimens left, next to the squirrel.

Figure 13 conjoined twins of Anas sp.

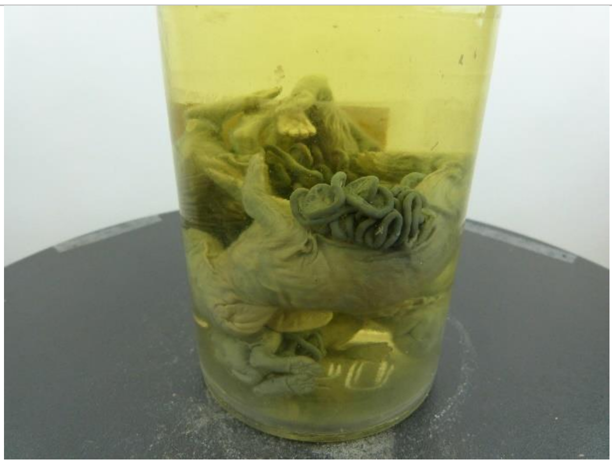
Glass container no. 25 features another set of conjoined twins. These specimens share their thorax and abdomen.[40]

[40] Presumably, the abdomen and pelvis are not completely fused – confer extremely wide gap between lower feet. Cephalothoracopagic are among the rarest cases of conjoined twins and feature conjoined thorax and upper abdomen but often two faces on a fused head. (Horakova et al. 2008)

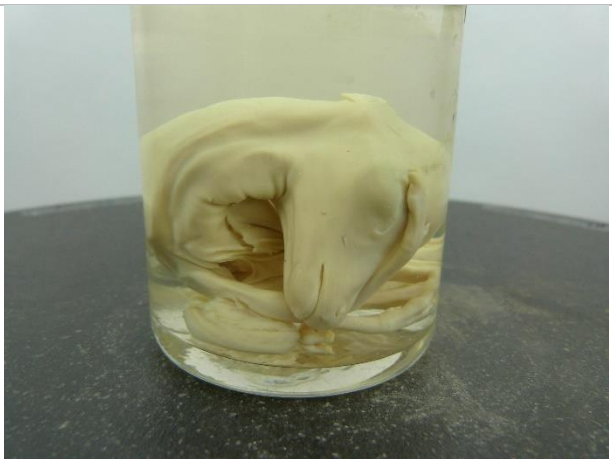
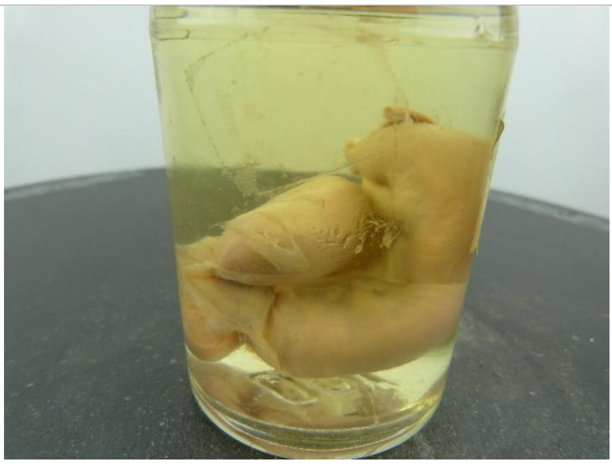
6.5. Embryos in Hyrtl's collection

No.	Pictures of objects	Additional Information[41]
p011		*Mus decumanus* "*Mus decumanus (albino)* *Uterus mit Embryonen*" The Label does not correspond with Hyrtl's handwriting and may have been added afterwards or the specimen is not part of Hyrtl's original estate.
p017		Rodentia "*Chalangista cavifreus (?)* Embryo fem. Amboina" Label does not correspond with Hyrtl's handwriting. Soft tissues removed
p024		*Didelphis lanigera* "*Didelphis lanigera* male Embryo Paraguay H. 38. (prov. No. 645)" Label seemingly refers to Hyrtl's old numeration. Soft tissues removed

[41] Information obtained from labels is given with quotation marks.

2119		*Ursus maritimus* "*Thalassarctos Polaris* Embryo" Umbilical cord is clearly visible
780		*Delphinus sp.* "Embryo v. *Delphinus sp.* im Uterus 1875"
p035		*Canis lupus fam.* "Hund Embryonen" Label does not correspond with Hyrtl's handwriting. Several specimens show sagittal cuts of the abdomen.

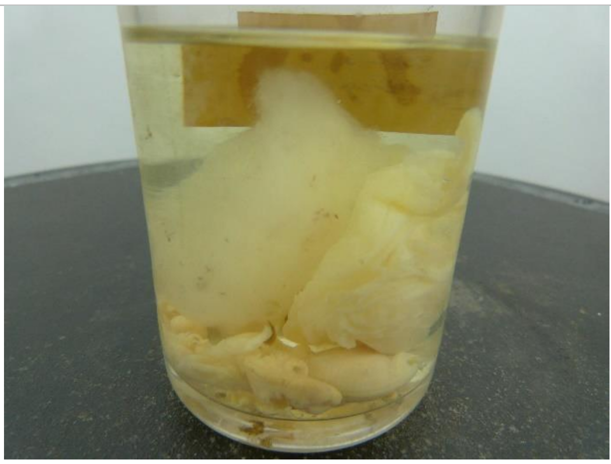
p036		*Canis lupus fam.* "[…]eca mar[…]" This Vessel contains three embryos showing sagittal cuts of the abdomen. The label is damaged but clearly of Hyrtl origin.
p040		*Hydrochoerus sp.* "Embryo zool. Institut. Wien" Label does not correspond with Hyrtl's handwriting.
P041		*Dasypus novemcinctus* "*Dasypus novemcinctus* L. S. Amerika" Vessel contains two specimens in total.

77		*Cervus virginianus* *"Cervus virginianus"* Sagittal and transversal cuts were performed on this specimen.
60		*Ovis aries* "*Ovis aries* Embryo" Label does not correspond with Hyrtl's handwriting.
p044		*Rattus sp.* "Ratte 1964 Uterus gravis" Not from Hyrtl's estate

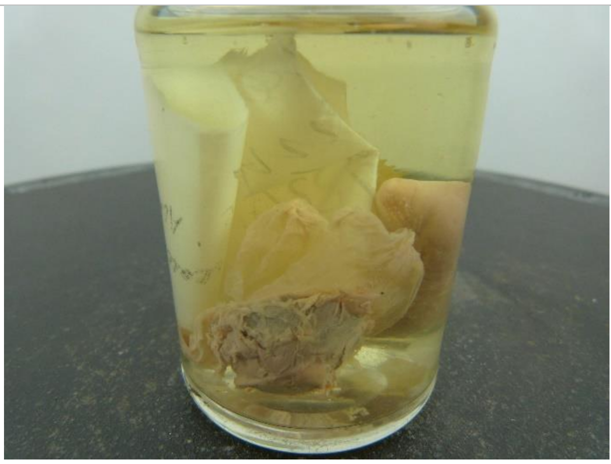
4037	Due to reasons of data protection and out of a sense of reverence, depictions of human specimens are not shown in this diploma thesis. If need be, please consult the department of theoretical biology at Vienna University.	*Homo sapiens* “*Homo male (Embryo 6 mens) Skelet.)”*
p045		*Canis lupus fam.* Label missing
2113		*Castor fiber* „*Castor fiber* (Embryo)“ Several abdominal preparations

3011	Depictions of human specimens are not shown due to reasons of data protection and out of a sense of reverence.	*Homo sapiens* "*Homo* male (infans 7 dier.) Pelvis, inframaxillare"
p046	Depictions of human specimens are not shown due to reasons of data protection and out of a sense of reverence.	*Homo sapiens* Label missing Embryo and placenta
p047		*Hydrochoerus sp.* Label missing Two embryonic specimens

4688/4690	Depictions of human specimens are not shown due to reasons of data protection and out of a sense of reverence.	*Homo sp.* “*Homo* (Embryo) Sceleti partes”
93		*Phocaena phocaena* “*Phocaena communis* Embryo”
p049		*Canis lupus fam.* Label missing Embryo and placenta

2107		*Tragulus napu* “*Moschus napu* Embryo“
3068		*Ovis aries* „*Ovis aries* 4 Embryones“
p050		*Canis lupus* cf. Label unreadable Umbilical cord clearly visible

2148		*Phoca vitulina* "*Phoca vitulina Embryo"* *Several specimens*
p051		Label missing Undetermined embryo in amniotic sac
4017	Depictions of human specimens are not shown due to reasons of data protection and out of a sense of reverence.	*Homo sapiens* "*Homo* (Embryo) female 7 Monate alt" Fontanelle is clearly visible (scalp removed)

p055		*Sus scrofa* Label damaged Umbilical cord and placenta visible
p057		*Erinaceus sp.* “Embryo *Erinaceus”* Label does not correspond with Hyrtl’s handwriting.
386		*Dasypus sexcinctus* “*Dasypus sexcinctus* L. female 4 Tage alt. S.Amerika” Head separated, several abdominal preparations

p058		Label missing Several embryos in amniotic sac
94		*Delphinus sp.* "*Delphinus phocaena* Embryo" Umbilical cord clearly visible
95		*Delphinus sp.* "*Delphinus phocaena* Embryo" This *Delphinus* shows a sagittal cut of the abdomen

p064		*Erinaceus europaeus* “*Erinaceus europaeus* female gravid. Org. urogenit. 2 embryones*”*
560		*Delphinus sp.* “Embryo von *Delphinus* (*phocaena*?)” The largest and most developed *Delphinus* embryo of Hyrtl’s collection at the Department of Theoretical Biology
636		*Tamandua tetradactyla* “*Myrmecophaga tamandua (tetradactyla L.)* Embryo. H. 65. (prov. K. No. 636)” Soft tissues removed

640		*Chalepus didactylus* "*Chaleopus didactylus* L. Embryo. H. 59. (prov. Kat. No. 640)"
4662		*Sus scrofa* "*Sus domesticus* Embryo" Embryo still in amniotic sac
2115		*Erinaceus europaeus* "*Erinaceus europaeus* Embryo" This *Erinaceus* is displayed without amniotic sac

307		*Embiotoca lateralis* “Uterus u. Embryonen *Jaeniotoca lateralis*” One of few fish specimens
797		*Lepus sp.* “*Lepus. sp?* Embryo” Embryo with placenta?
2906		*Bos taurus* “*Bos taurus* female Org. gen. et uropoet. embryones bigemini“

2155		*Equus ferus* „*Equus caballus* Embryo“
517		*Crocodylus acutus* “*Crocodilus acutus* visc. embrio. et oculi”

6.6. Other specimens and collectors

Apart from Embryos and “monstrosities” Joseph Hyrtl also left behind many other specimens. Among these are certain organ preparations such as preparations of lungs, eyes, or kidneys.

Figure 14 Vessel no. 189 exhibiting “Cor et pulmones” in Wallabia bicolor.

In his “Lehrbuch der Anatomie des Menschen” Joseph Hyrtl discusses arterial and capillary vessels in erectile tissues. Herein he discusses anastomoses in blood vessels and states that he established that most arterial vessels in “corporae cavernosae” never end in capillary vessels but rather end in veins – a phenomenon he also describes for tissues in bat thumbs. (Hyrtl 1846) What Hyrtl discovered through his corrosion anatomy in Vespertilionidae, Gasser and others discovered for other phalanges in bats and unrelated animals such as rats, cats, mice or dogs. (Clara 1956)

Figure 15 Glass jar no. 298 contains a specimen of V. velatus - one of many bat species found in Hyrtl’s collection. The label bares Hyrtl’s own handwriting

Many other bat specimens in this collection were provided by Franz Spillmann (1901-1988), who was an Austrian zoologist and paleologist who collected specimens and taught in South America and is mostly known for his books on extinct canines, birds and elephant species but moreover collected many small mammals including bats while studying in Vienna. (https://www.zobodat.at/personen.php?id=8111&bio=full, last visited: 12.5.2018) About ten specimens[42] in this collection are of Spillmann origin.

Figure 16 Container no. P032 contains various bat specimens and a typical Spillmann label.

Other providers for this collection include biologists Desbalmes, Harmühlner, Neidhart and Kriwet.[43]

[42] In this case, exact numbers cannot be given since many specimens lack their labels and only provide their numeration (which in some cases matches the style of numeration in Spillmann's specimens)

[43] Each provided one specimen.

7. Designing an e-learning tool

The “Kompetenzmodell Biologie” is a guideline for Austrian biology teachers. It obligates the teacher to adjust his syllabus to enable science students acquiring necessary competences for scientific exchange. The “Kompetenzmodell” consists of three dimensions. The “Handlungsdimension” (dimension of operability)[44] enables the student to observe and explain natural phenomena, conduct scientific research and analyze scientific data to make conclusions.[45] (BMBF 2012)

Technical innovations have drastically changed the way students are taught in the 21st century. In the age of WhatsApp and online dictionaries, information is far easier accessible. On the other hand, smartphones and similar technologies are often distractions and schools should decide how to benefit from and how to include technical advancements. (Zorn 2018) Interestingly, the change in didactics and media is not sufficiently represented in Austria’s “Lehramtsstudien” (teacher training programmes) as university courses on media education and media didactics are scarce and often inadequate in the Universities’ curriculum. (Swertz 2015)

[44] The dimension of operability is constrained by the student’s level of educational requirement and the “Inhaltsdimension” (dimension of content). The latter roughly consists of the curriculum. (BMBF 2012)

[45] Every unit of a lesson should incorporate the operability dimensions. (BMBF 2012)

The use of media in schools nonetheless provides several advantages. While students certainly boost their capabilities of media use, the use of media in classrooms brings motivational assets and strengthens student cooperation, cognitive complexity and self-organization. (Herzig 2014)

7.1. Concept

The concept for this e-learning tool was designed for “Wahlfach Biologie” (elective subject biology)[46], eighth grade “Gymnasium” (ann.: an Austrian school type similar to high school) or similar educational stages and institutions.

The curriculum for eighth grade Austrian high school students (the twelfth and last grade in Austria’s school system) provides for education in “chemical and biological evolution”, an “insight in evolutionary theories” and an “overview of developmental history”. (BMBWF 2016)[47]

The e-learning tool aims at introducing evolutionary concepts and the possibility to understand and discover evolutionary patterns from different viewpoints and by studying different disciplines. To be integrated in biology lessons the implementation and discussion of this sequence should (due to reasons of practicality and implementability) not exceed one lesson.

[46] Elective subjects of Austrian high schools offer great curricular liberties.

[47] Bundesministerium für Bildung, Wissenschaft und Forschung https://bildung.bmbwf.gv.at/schulen/unterricht/lp/lp_neu_ahs_08_11860.pdf?61ebyv, last visited: 1.6.2018)

Figure 17 Introduction. "Discover evolution through different paths".

The e-learning tool focuses on Joseph Hyrtl's comparative anatomy and explains how Hyrtl came to his conclusions. Nonetheless, different viewpoints are offered and explanations are given as to why several biological disciplines can lead to the same understanding of evolution.

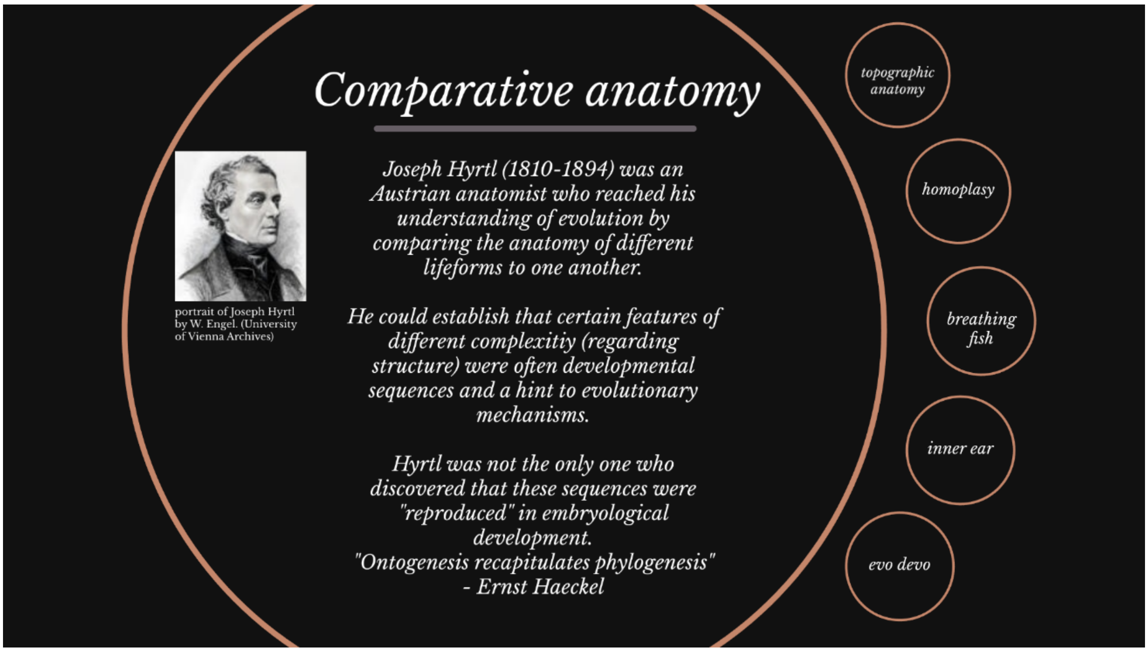


Figure 18 „Comparative anatomy"

As the concept of this e-learning tool is derived from Joseph Hyrtl’s approach to comparative anatomy, the most important explanations are given through his viewpoint or the viewpoint of like-minded individuals of his lifetime. Therefore, this application starts with an introduction to Hyrtl’s approach and credo.

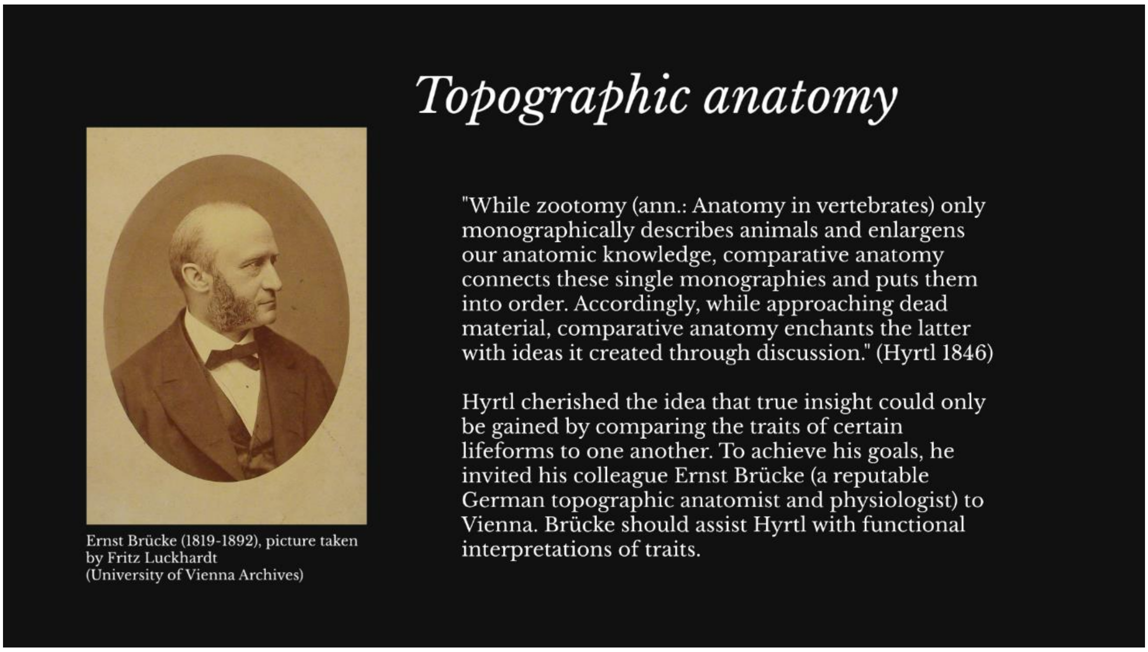


Figure 19 “Topographic anatomy” in contrast to comparative anatomy

As Hyrtl explained in his “Lehrbuch der Anatomie”, while zootomy only describes traits of certain lifeforms, comparative anatomy puts them into order. Therefore, conclusions (he also considered this valid for phylogeny) could only be drawn when similar traits of different species were put into contrast. Since Hyrtl invited Ernst Brücke to Vienna to elaborate on the functionality of traits, an insight to their collaboration is given.

Moreover, the tool provides students with fundamental biological terms that are relevant for evolutionary discourse and enables students to debate in scientific disputes. In this case, the term homoplasy is elaborated, and related terms such as apomorphies, plesiomorphies, convergent and divergent evolution are explained using the example of “extremities” in otters, bats and flies, and moreover the varieties of adaptations that enable bats and flies to fly.

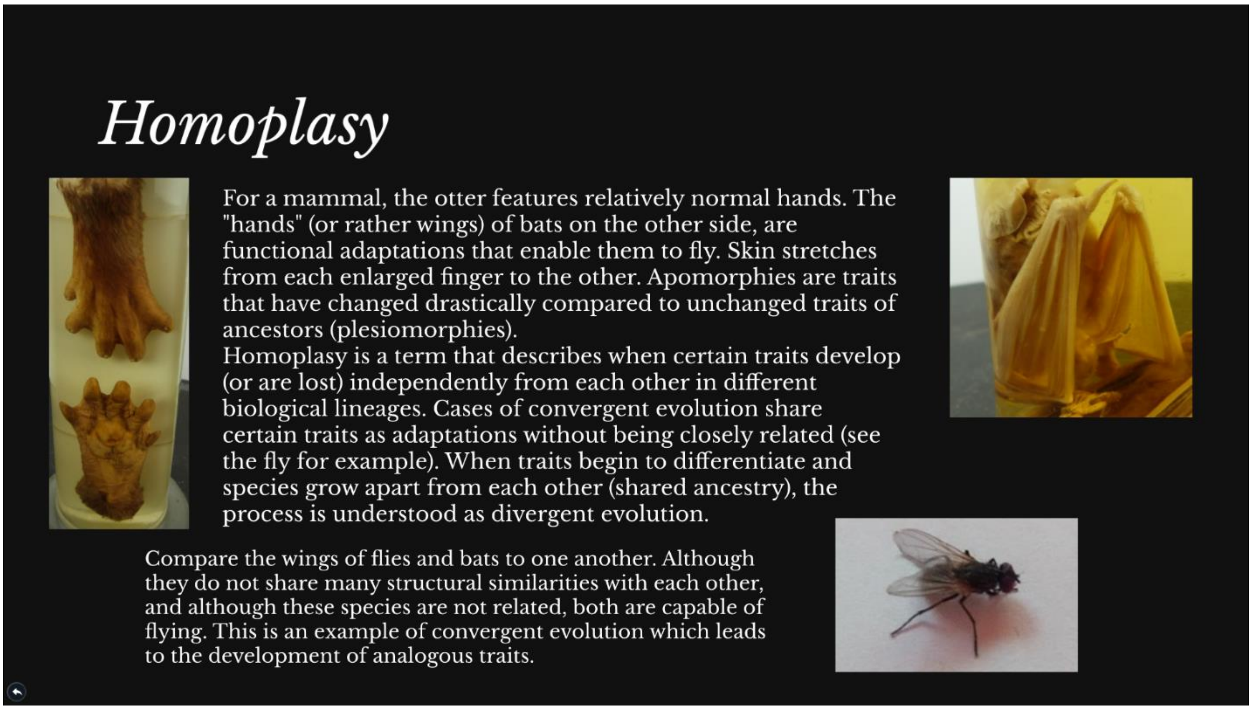


Figure 20 “Homoplasy” – Discussing convergent and divergent evolution in extremities of vertebrates and insect wings.

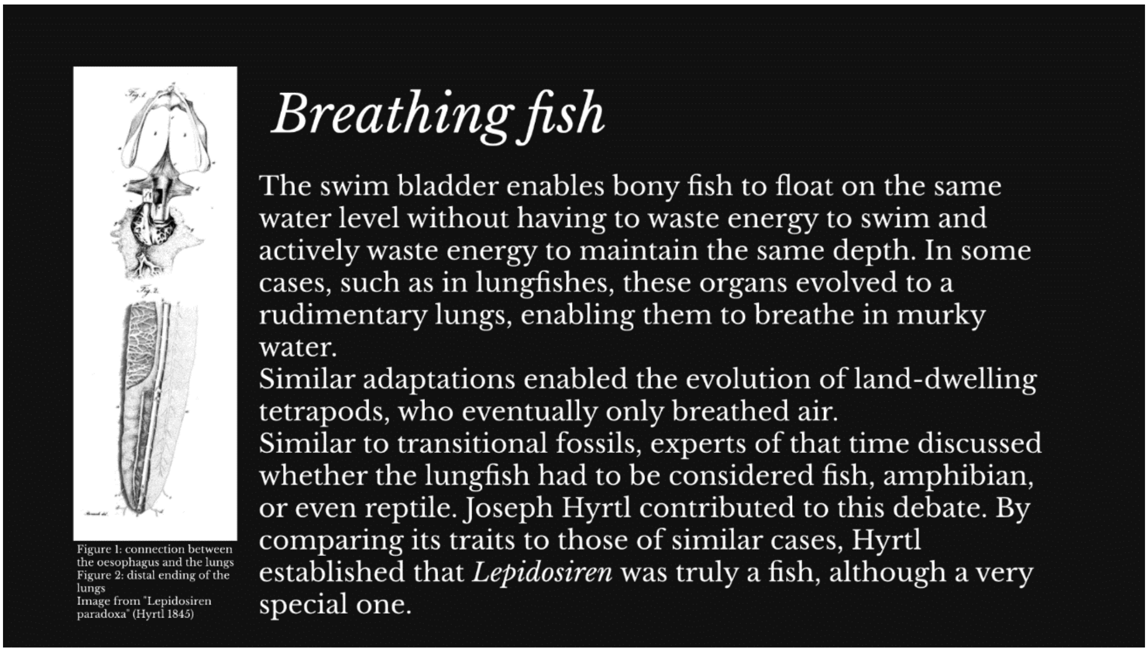


Figure 21 “Breathing fish” – the evolution of lungs

As explained in chapter 4.1., Hyrtl established the ichthyic nature of *Lepidosiren paradoxa* by comparing certain traits, e.g. the position of the bladder in relation to the urogenital opening, to showpieces of fish and amphibia, and therefore concluded, that *Lepidosiren* was truly a fish. Accordingly, and based on this 19th century dispute, the role of transitional adaptations and fossils is explained with the addition of a copper engraving from Hyrtl’s book “Lepidosiren paradoxa”.

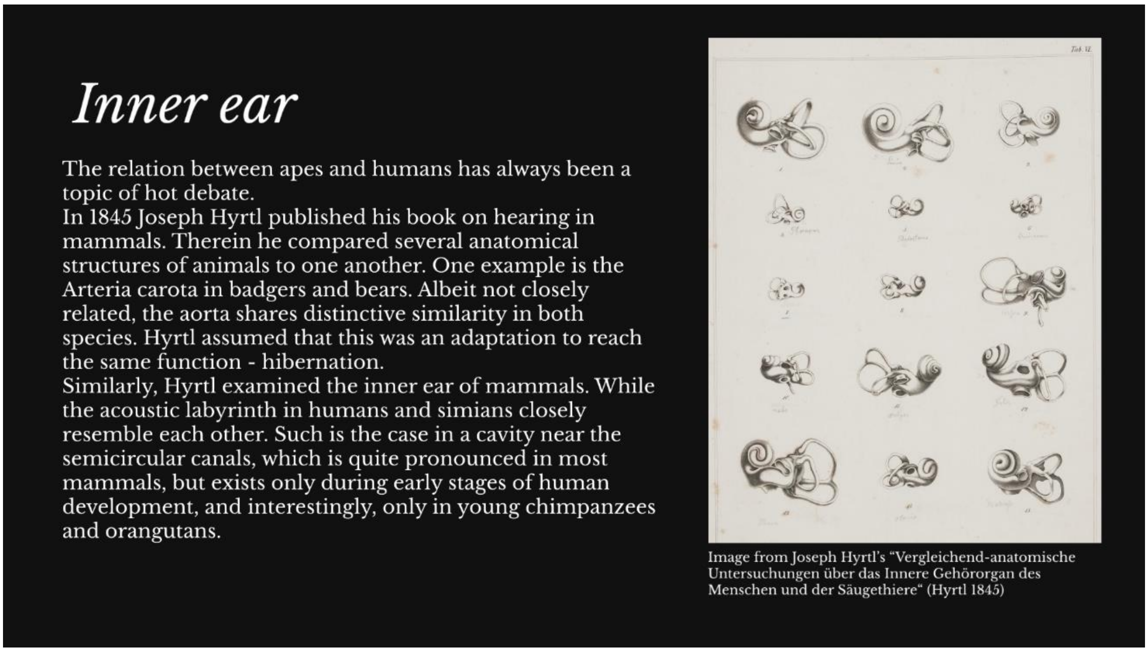


Figure 22 "Inner ear" – comparing the acoustic labyrinth of simians and humans

Another example of Hyrtl's comparative work is his book on hearing in mammals. As already explained in chapter 4.2., Hyrtl concluded on the adaptation of A. carota in *Ursus* and *Meles* to hibernation. Similarly, the unique form of the semicircular canals in humans and simians in distinction to most other mammals is explained in this part of the e-learning tool. The llustrations of the inner ear are taken from Hyrtl's "Vergleichend-anatomische Untersuchungen über das Innere Gehörorgan des Menschen und der Säugethiere".

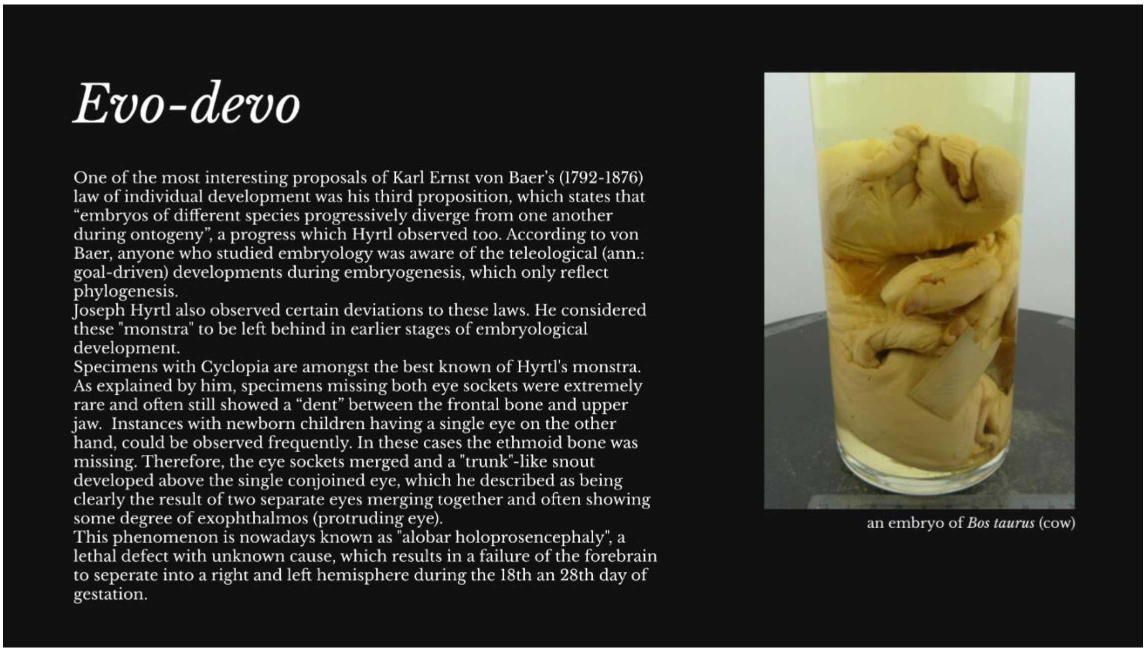


Figure 23 "Evo-Devo" according to Karl Ernst von Baer and Hyrtl's thoughts on his "monstra"

As his thoughts on "monstra" are intuitively accessible through his embryological collection, Joseph Hyrtl's thoughts on his "aberrations", e.g. his belief that these specimens were left behind in earlier stages of embryological development, are compared to Karl Ernst von Baer's third law of individual development. Clearly, Hyrtl too was aware of the recapitulation of phylogeny in ontogeny as stated in chapter 5.

A multiple-choice test with live scoreboard constitutes the last part of this mockup. In this sequence, learnt concepts are put to the test. Simultaneously, students gather points by answering the questions. A live scoreboard is provided to give indications for grading or evaluation.

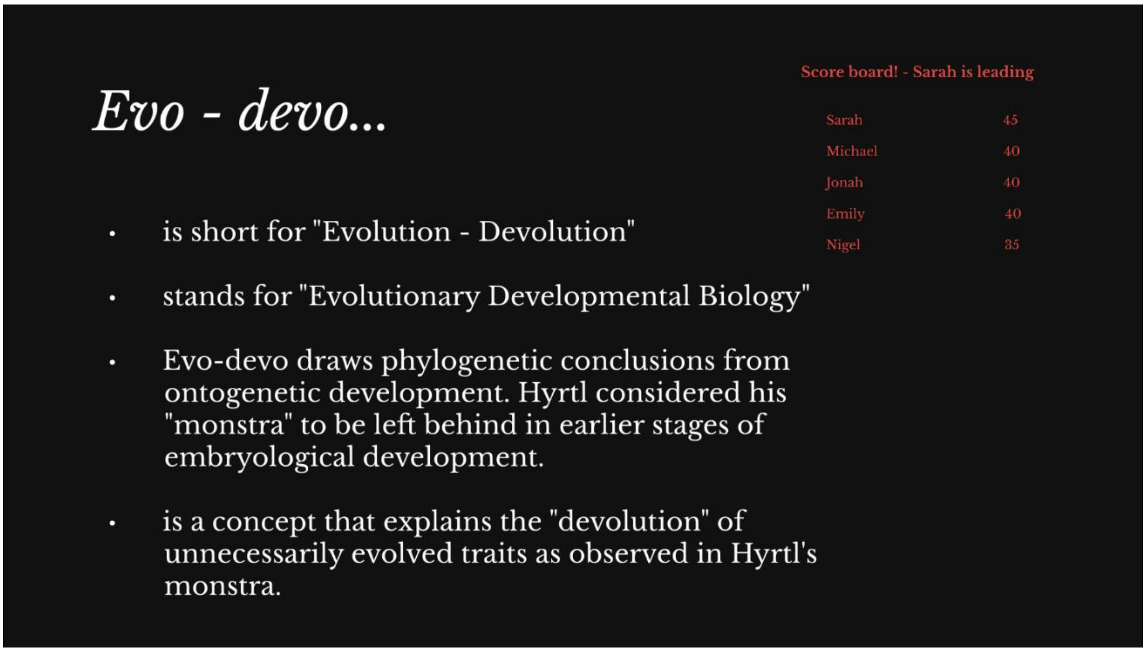


Figure 24 "Evo-devo..." an exemplary question for the design of the last sequence of this application

This tool covers all parts of the “Handlungsdimension” provided by the BMBF. To be able to observe and explain evolutionary patterns, an introduction into this field through the perspective of comparative anatomy is given. By providing fundamental terms and presenting evolutionary concepts, students could conduct ensuing scientific research. As examples for evolution are given, students are enabled to make their own conclusions.

8. Abstract

Joseph Hyrtl's embryological collection consists of 446 different specimens, held at the zoological collection of the University of Vienna's department for theoretical biology. The collection features 44 embryological preparations and hundreds of organ preparations and unaltered specimens of different origin. Among these specimens are a handful of “monstrosities” collected by Hyrtl himself. The Austrian anatomist considered these specimens to be left behind in earlier stages of development.

In the middle of the nineteenth century Joseph Hyrtl taught at Prague's Charles University and the University of Vienna. A strong supporter of the catholic church, Hyrtl soon began to grasp his own approach to evolution by dedicating himself to comparative anatomy. Several anatomical disputes led Hyrtl to compare traits of strongly debated species to one another and led him to the conclusion that man was not created but gradually developed from “lower” lifeforms.

Hyrtl himself stated that evolution was already an established fact during his lifetime and that evolutionary theories were already being proposed by others.

The aims of these diploma thesis were to elaborately illustrate Hyrtl's ideas and theories. The intention behind digitization of his embryological collection was to facilitate intra- and interdisciplinary discourse and to explain, how Hyrtl's ideas are reflected in the collection he used for public display and educational purposes.

As these specimens were once used for education and as Hyrtl's approach offer an alternative to the well perceived Darwinist approach, the last step of this diploma thesis was to design an e-learning tool for use in Austrian high schools.

9. Zusammenfassung

Joseph Hyrtl war ein österreichischer Anatom, welcher im neunzehnten Jahrhundert in Prag und Wien wirkte. Das Department für theoretische Biologie an der Wiener Universität verfügt über eine atemberaubende Anzahl an Präparaten und biologischen Schaustücken. Joseph Hyrtls embryologische Sammlung macht einen nicht zu unterschätzenden Teil der Feuchtsammlung aus. Sein Nachlass besteht aus 446 verschiedenen anatomischen Präparaten und Einzelstücken, welche auch zu Lehrzwecken verwendet wurden. Vierundvierzig Sammlungsstücke sind dabei als embryologische Präparate zu vermerken. Der Rest der Sammlung besteht aus ebenso wertvollen adulten Exemplaren und Präparationen, sowie einer Handvoll an „Monstra“, wie Hyrtl sie nannte. Exemplare dieses Typus schrieb Hyrtl Fehlentwicklungen in der Embryonalentwicklung zu.

Obwohl der österreichische Anatom ein Anhänger der katholischen Kirche war, beschäftigte er sich mit vergleichender Anatomie und kam durch seine Arbeit und durch sein Wirken zu dem Schluss, dass die Evolution ein nicht abzustreitender Fakt ist. Wie Hyrtl selbst festhielt kamen auch Andere zum selben Schluss.

Da sich Hyrtl’s Überlegungen und Herangehensweisen bestens eignen um einen anderen Zugang zur Evolution zu gewinnen, war ein Zielbereich dieser Diplomarbeit die zum Zwecke des vereinfachten Zugangs und zur Erleichterung des inter- und intradisziplinären Diskurses digitalisierten Sammlung in ein E-learning Tool aufzuarbeiten und mit Hyrtls Ideen zu verknüpfen. Dadurch soll Gymnasialschülern eine alternative Herangehensweise zu Darwins Evolutionstheorie geboten werden.

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