Countering revisionism—part 2: Ernst Haeckel and his triple-woodcut print

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Ernst Haeckel is well known for his fakery of embryos in the *tailbud* stage of development. There is also the earlier issue of where Haeckel illegitimately reprinted the same woodcut three times, alleging these three illustrations represent different animals, while drawing conclusions from the (artificially created) similarities. One historian makes a serious attempt to excuse Haeckel, yet further analysis shows Haeckel's deception is even worse than was previously thought.

Ernst Haeckel (1834–1919) was a controversial German scientist, who was qualified as a zoologist and a medical doctor, as well as being passionate about marine biology in particular. For more than a century, Haeckel has been under scrutiny by both evolutionists as well as non-evolutionists. In 1997, fury against Haeckel raged anew when a team of embryologists published photographs of actual vertebrate embryos at the so-called 'tailbud' stage of embryonic development. These showed a gross discrepancy between the pictures Haeckel propagated to the public by his wildly popular evolution books and lectures, and the actual data.[1] Creationists[2] and honest or informed evolutionists[3] were furious, and Haeckel's reputation rightfully became even more tarnished than before.

In 2008, however, Robert John Richards, a distinguished historian at the University of Chicago, made a serious attempt to rehabilitate the name of Ernst Haeckel.[4,5,6] In *Countering revisionism Part I,*[7] we refuted Richards's attempt to exonerate Haeckel from the charges of fraud or deliberate distortion in regard to these tailbud stage embryos. However, even though those are of primary importance, they are by no means the only such issue we need to look at. In this paper, we will look at another issue at hand which questions Haeckel's honesty as a scientist, and which also generated controversy around Haeckel during his lifetime.

Introduction to the 'woodcut problem'

One of the first troubles in Haeckel's career concerned illustrations in the first edition (1868) of what would become his wildly popular book, *Natürliche Schöpfungsgeschichte*.[8] When the Swiss zoologist, anatomist and palaeontologist Ludwig Rütimeyer reviewed the book in 1868,[9] he noticed that Haeckel had used the *same woodcut* to print animal embryo illustrations of three (quite) *different* types of animals. We must point out that the problem is also that Haeckel tried to *draw conclusions* from these *artificially* created similarities. In this case, Haeckel's illustrations purported to represent a *dog*, *chicken,* and *turtle* embryo at what Haeckel coined to be the Sandal-stage (see figure 1).

The 'Sandal-stage' is an old term for the neurula embryo.[10] This is the phase when neurulation begins, i.e. the neural plate forms, then folds to form the neural tube, the precursor to the brain and central nervous system. It is also important to note that these embryos are generally in an *earlier stage* than the usual Haeckelian embryos which we sometimes still find in various textbooks in *modern times*. All this caused immense (and appropriate) disapproval and criticism as being misleading and unscientific. Rütimeyer was only the first of many people to launch complaints against Haeckel. Naturally, Robert Richards spends some considerable time and space defending Haeckel against the critics which he picked up over this particular episode.

Basis of claims

We will first treat the basic claims around these woodcuts in a (2008) Richards paper named *Haeckel's Embryos: fraud not proven*. Where space allows, we will further consult claims in his book called *The Tragic Sense of Life: Ernst Haeckel and the Struggle Over Evolutionary Thought.* In this paper, Richards tells his readers:

> "In the first edition (1868) of his wildly popular *Natürliche Schöpfungsgeschichte* (*Natural History of Creation*), he used the same wood cut three times to represent the initial formation of embryos of dog, chicken, and turtle. When a reviewer noticed this (Rütimeyer 1868), Haeckel defended himself by arguing you could not tell the differences among these vertebrates at this very early-stage [sic]; and given the instrumentation at the time, this was true. He nonetheless recognized that he egregiously erred and immediately corrected the text in the next edition two years later."[11]

Instrumentation of 'that time'

As above, Richards claims that one would not have been capable of seeing the differences between these embryos in neurulation due to the instrumentation of the time. He repeated this claim less directly in his book: "at these very early stages the morphology of higher vertebrates appears essentially the same, at least as resolvable with mid-nineteenth-century equipment".[12] This claim is frankly astounding—for several reasons, and we will show why it is ultimately false.

A brief history of the microscope in the 1st half of the 19th century[13]

The microscope and optical methods or instrumentation went through remarkable development and improvement during the Victorian era. This meant that microscopic objects could now be seen clearly and distinguishably under the microscope, whereas in previous times, such objects were blurred and the images surrounded by coloured 'fringes'. Indeed, by the 1830s, it became possible to construct lenses in which this chromatic aberration was largely corrected. Objects viewed under the microscope were also corrected for spherical aberration, as a result of the work of Joseph Jackson Lister (1786–1869).[14]

As a result of the very clear images from the achromatic, compound microscopes, microscopic studies of plant and animal tissues were now starting to take the high ground. Instruments from the 1830s and 1840s were now superior to previous microscopes (especially from the pre-achromatic days), and could by this stage reach a maximum resolution of about 1 µm. (This figure was obtained by Pieter H. van Cittert,[15] using a Nobert test plate.[16]) This is smaller than many eukaryotic cell *components*—e.g. nucleus, nucleolus, wall thickness, vacuoles, some mitochondria—let alone the whole cell.

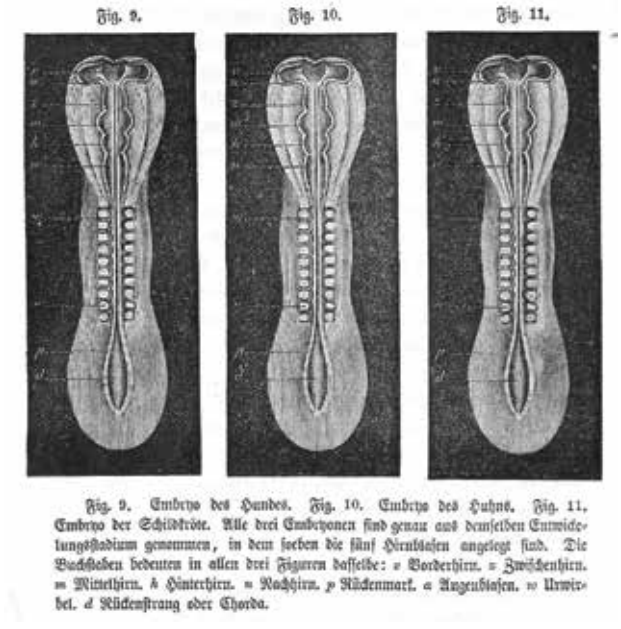

Figure 1. The infamous triple woodcut in Haeckel's book *Natürliche Schöpfungsgeschichte* (1868). Haeckel alleged the same woodcut represented a dog, chicken, and turtle.

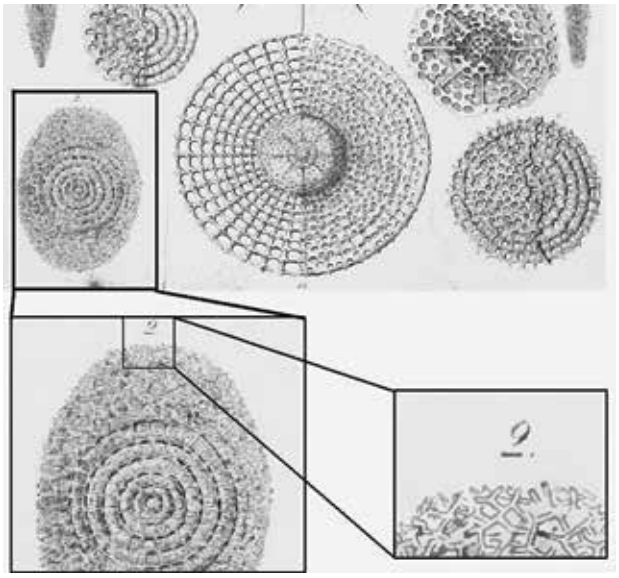

Figure 2. A part of Plate XXVIII of Haeckel's 1862 monograph on the Radiolaria.[22] Here we zoom in on the number 2, noticing that Haeckel even paid attention to many fine details of these single-celled organisms such as spicule-like structures.

An important landmark for the history of microscopy occurred when 17 gentlemen met on 3 September 1839. As a result of this, the 'Microscopic Society of London' was formed, which soon reached 115 members, with the famous anti-Darwinian anatomist and paleontologist Richard Owen (1804–1892) as its first president. The society later received Royal Charter when it became known as the Royal Microscopical Society. This provided *much* incentive for instrument makers to develop better instruments. From here on, the microscope made several upward developments by several instrument makers in several countries.

Contradiction to other claims by Richards himself

In an earlier 2004 essay on Ernst Haeckel, Richards tells his readers the following in regards to the young Haeckel as a medical student at Würzburg, under Swiss anatomist and physiologist Albert von Kölliker (1817–1905):

> "Kölliker taught histology and introduced Haeckel to what would quickly flower into a sweet delight …
>
> "Under the affable tutelage of Kölliker, he [Haeckel] grew to love precise work in histology, especially since he had a talent with the microscope. He could

simultaneously peer with one eye through the lens and with the other draw in exquisite detail the minute structures of tissues. 'Vivant cellulae! Vivat Microscopia!' he exulted to his father at Christmas 1853."[17]

Richards also repeats these claims *verbatim* in his book.[18] To anybody who knows that histology is the study of microscopic anatomy of cells and tissues of plants and animals, a patently obvious question must surely come to mind: *if* the instrumentation and mid-19th century equipment were allegedly *too* poor or *insufficient* to see differences between already *multi-cellular* neurula-embryos, how, then, would it have been possible for both Haeckel as a student, as well as his professors and lectures, to study histology? It is even more astounding that Richards makes this claim about instrumentation in order to excuse Haeckel, when he himself reveals that Haeckel was so talented with the microscope, and so skilled with making drawings from what he saw.

Moreover, Haeckel's medical studies took place during the 1850s, while the infamous triple woodcut pictures were published in 1868. One could also not resist the temptation to point out that Richards tells us that Haeckel took private tutorials in microscopy with Franz Leydig (1821—1908).[19] Leydig discovered what are known even today as Leydig cells (not mentioned by Richards). These are found in the testes, and play an important role in releasing a class of hormones called androgens. Leydig discovered these cells in 1850,[20] which is again much earlier than 1868, the time at which Richards alleges one could not tell the differences in embryos due to instrumentation! Richards thus tries to advance his pro-Haeckel arguments on the basis of his readers' ignorance about the history of the microscope and 'instrumentation'.

Haeckel and the Radiolarians

If there is one thing which also shows the nonsensical nature of the claims that a) the instrumentation of Haeckel's time was insufficient and b) Haeckel was only merely 'sloppy' with his embryo sketches, it is Haeckel's extensive work on the Radiolarians. These are protozoa (single-celled eukaryotes) which secrete beautiful exoskeletons known as 'tests'. During his career, Haeckel classified literally thousands of them. The monograph which first made him famous appeared in 1862.[21,22] Of this, Richards fondly tells us that:

"… he [Haeckel] provided the most careful description of the distinguishing characteristics of the skeletons and soft parts, including *extraordinarily exact measurements* [emphasis added]."[23,24]

Indeed, if we look for example at illustration number 2 of Plate XXVIII (of his 1862 monograph), we see that Haeckel took care to even illustrate the fine, spicule-like structures of the protozoon (see figure 2)!

Did Haeckel *really* improve?

Richards is proud to tell us that Haeckel "… nonetheless recognized that he egregiously erred and immediately corrected the text in the next edition two years later." But we must ask: Did Haeckel *really* fundamentally improve, or did he just become more 'clever' in his ways? The answer is in some regards remarkable: although he did not repeat the woodcut in a printed sequence again, he still used it in a singular print for countless editions to come in *Natürliche Schöpfungsgeschichte* (see figure 3). In the *text* of these later editions, Haeckel tells his readers about this woodcut (though now only printed once) that:

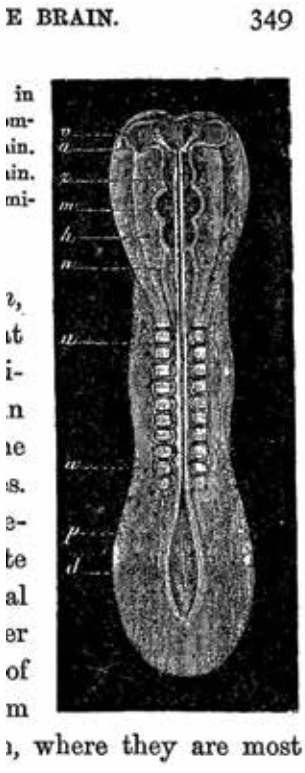

Figure 3. Haeckel's singular reproduction of the same woodcut in later editions of his popular book *Natürliche Schöpfungsgeschichte*.[25]

"The thickened disc, or foundation of the embryo, soon assumes an oblong, and then fiddle-shaped form, in consequence of its right and left walls becoming convex (Fig. 7, p. 349). At this stage of development, in the first form of their germ or embryo, *not only all mammals, including man,* but even *all vertebrate animals in general—birds, reptiles, amphibious animals, and fishes—can either not be distinguished from one another at all*, or only by very unessential differences, such as size and the arrangement of egg-coverings [emphasis added]."[25]

Haeckel repeats this claim again more or less just after this woodcut illustration, when he says that:

"In the early stage of development which is represented in Fig. 7, it seems as yet *quite impossible* to distinguish the embryos of the different mammals, birds, and reptiles, from one another [emphasis added]."[26,27]

So let us get clarity about what Haeckel is really saying to his readers in the later editions: he now not only alleges that this woodcut represents exactly what

a *dog*, *chicken,* and *turtle* look like at this stage. No, now he alleges in the text of the book that *all* mammals as well as *all* vertebrates, including fishes and amphibians look like that woodcut at the neurula-stage. In principle, that is not at all an improvement; in fact, it is actually far *worse*! The embryo woodcut just wasn't physically reprinted again. But this visual representation (the woodcut) has now been stretched even further!

Richards' false premises, and why embryos at these early stages (including at neurulation) do not appear nearly identical

What is remarkable is not only Haeckel's assertions, but also the false premises on which Robert Richards bases his whole defence of Haeckel and his scholarship. In his book, Richards tells his readers that:

> "… aside from the size of eggs or of embryos, at these very early stages the morphology of higher vertebrates appears essentially the same, at least as resolvable with mid-nineteenth-century equipment."[12]

In the same paragraph, the supposed similarity in the early stages of embryonic development is stated as fact:

> "… given the circumstances of a popular presentation [of evolution] and the *fact* that embryos at these early stages cannot be distinguished [emphasis added]".

Then, in the next chapter which is dedicated to defending Haeckel against his critics, Richards again tells us:

> "… [given] the fact that morphological structures of vertebrate eggs and early embryos are almost impossible to distinguish… ."[28]

So Richards *himself* believes that embryos are nearly identical or indistinguishable in the earlier stages. Yet nothing could be further from the truth! Had Richards himself bothered to look at *basic* comparative embryology, he would have found that different animal groups display *different* developmental patterns, even from the *earliest* stages.

Even pregraduate students of zoology or biology, taking courses in embryology would typically get to compare, using four or so animal groups, such things as the embryo's cleavage and blastulation, gastrulation, and neurulation.

Take for example mere cleavage and blastulation, where the fertilized egg, called the zygote, starts to undergo cell division (and in some cases forms a hollow ball, called the blastula). In the Branchiostoma, we observe *equal holoblastic cleavage*; in amphibians, we observe un*equal holoblastic cleavage*. In reptiles and birds, we observe a *discoblastic* pattern and in most mammals, and humans specifically, we find *rotational cleavage*,[29] which leads to a *trophoblastic* pattern.[30]

These different patterns also make these embryos visually distinct—indeed, pregraduate students must be capable of identifying these embryos (based on their differences) in the laboratory, and low magnification is sufficient. And these stages are still long before the stage where embryos undergo neurulation, yet differences are already visible. Robert Richards is thus flat out wrong, and he uses this *wrong premise* to fence off Haeckel's critics. Ironically, a careful reading of Haeckel's works in general reveals that Haeckel *himself* was aware of differences in early developmental stages such as cleavage and gastrulation.[31]

Returning to the embryos in neurulation, which Haeckel referred to as in the Sandal stage, again, we can make comparisons between the above four groups of creatures, for example, and find they are *not* visually the same or virtually identical, let alone 'quite impossible to distinguish from one another', as Haeckel asserted.[32] We can further look more specifically at species or genus level, and come to the same conclusion (see this footnote[33] for extensive documentation).

Since Haeckel extended this woodcut to *all* vertebrates from the second editions of *Natürliche Schöpfungsgeschichte* and onwards, it is worthwhile looking at an example or two which break the visual pattern sufficiently. Amphibians in general and frogs[34] in particular, as well as lungfishes (Australian,[35,36] South American, and African[37]) are indeed clearly distinguishable from the woodcut Haeckel printed (see figure 4). This is true of overall impressions, which are distinctive enough, as well as finer detail, to which Haeckel did pay attention. For example, on this particular woodcut, he marked certain primitive features, explaining them in the caption as follows: *Fore brain (v), Twixt brain (z), Mid brain (m), Hind brain (h), After brain (n), Spinal marrow (p), Eye-bladder (a), Primitive vertebrae (w), Spinal axis or notochord (d)* (see figure 3).[38] Interestingly enough, it seems to be exactly in the visual representations of some of these very structures that we also find differences, if we compare this woodcut to illustrations of other animals,

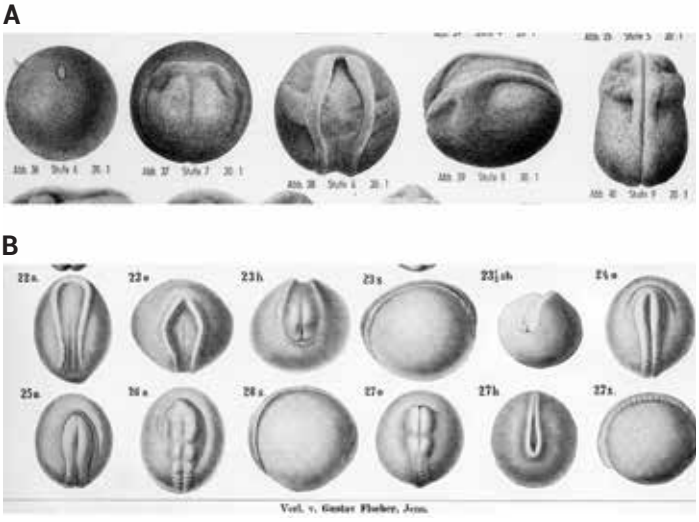

Figure 4. Two examples of animals which clearly break the visual pattern—taken from old literature. **A)** Common frog (*Rana*).[50] **B)** Australian/Queensland lungfish (*Neoceratodus*)[35] in the relevant period of development.

which were produced by contemporary scientists of Haeckel's time. Haeckel's woodcut seems to be that of a placental mammal. He cannot be salvaged by claiming ignorance of these details. He indeed paid attention to them!

One last relevant criticism to be made against both the original triple woodcut print and the print in following editions is that the *chick* embryo at this stage should clearly display a developing heart ventricle, as well as other primordia at the atrial level.[39] Again, we find clear demonstration of these features even in Haeckel's own time and country. Figure 5 shows a chick embryo illustration of an 1882 book by Arnold Brass,[40] who himself borrowed it from Haeckel's teacher Albert von Kölliker. But Haeckel's woodcut has no trace of the heart, and there can be no excuse for leaving out such an essential feature.

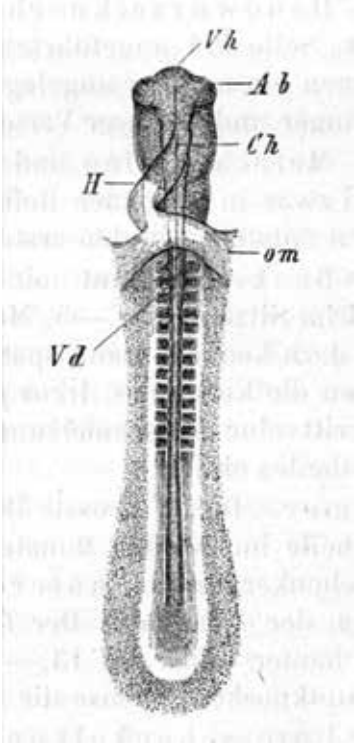

Figure 5. Chick embryo at more or less the same stage as Haeckel's woodcut, from literature of Haeckel's own time and country. Here we can clearly see developing heart structures. (From Brass[40]).

Heterochrony

There is one last proverbial spanner in the wheel to wreck the Haeckel/Richards claim that all vertebrate embryos are nearly identical at the earlier stages of development. This is the principle of *heterochrony*. This is an evolutionary term which indicates changes in the time of appearance of, or rate of development of, specific anatomical characteristics and features in the embryo.[41,42] This can practically translate into one holding a certain parameter (in embryonic development) constant over a range of different kinds of vertebrates (for example the number of somites or pharyngeal arches, or appearance of organs etc.), while finding that other parameters or features will then differ considerably between these vertebrate sample species.

Indeed, the famous 1997 Richardson *et al*. paper which also dropped the bomb on Haeckel's 1874 sequence of 'tailbud' embryos, has the title, of which the first part reads "There is no highly conserved embryonic stage in the vertebrates", and heterochrony is also discussed in this paper.[1] An earlier paper of Richardson named *Heterochrony and the Phylotypic Period* presents even more problems with defining any clearly conserved 'stage' in which embryos vary very little from one another—because heterochrony obscures such conservation.[43] It seems from these papers than heterochrony is the rule, rather than the exception. So we know that Haeckel's illustrations and conclusions could *not* have come from nature.

Of course, the natural question arises as to whether Haeckel himself was in any way aware of this phenomenon. The answer is a remarkable 'yes'! The word *heterochrony* was coined by none other than Haeckel *himself*, and used to describe "exceptions" to his theory of recapitulation.[44] (It was one of Haeckel's many neologisms, which include phylum, anthropogeny, ecology, stem cell, Protista, phylogeny, and ontogeny.) And there is a good indication that he made original contributions to the topic himself![45]

Legitimate schematizations?

Both Haeckel and Richards allege that Haeckel's embryo illustrations are simply legitimately 'schematized' illustrations. Haeckel states (as quoted by Richards):

"I believe that for didactic purposes simple schematic figures (especially for a larger public) are far more useful and instructive than illustrations that are as faithful to nature as possible and most carefully executed."[46]

Later in his book, Richards himself endorses this view (first stating the false premise that these embryos really are almost impossible to distinguish from one another):

> "… it might seem a reasonable economy to replicate the same images and use them as a device to pound home the message in a popular work meant for a nonprofessional audience"[28]

However, the famous palaeontologist (and anticreationist) Stephen Jay Gould (1941–2002) came to exactly the *opposite* conclusion about literature and illustrations for non-experts. He comments on similar reasoning by others, as follows:

> "But I confess to raging fundamentalism on this issue. The smallest compromise in dumbing down by inaccuracy destroys integrity and places the author upon a slippery slope of no return."[47]

And in regard to Haeckel's own illustrations, Gould makes the following important points:

> "This practice cannot be defended in any sense, but distortions in technical monographs cause minimal damage, because they rarely receive attention from readers without enough professional knowledge to recognize the fabrications. 'Improved' illustrations masquerading as accurate drawings spell much more

> trouble in popular books intended for general audiences lacking the expertise to separate a misleading idealization from a genuine signal from nature."[47]

And *contrary* to how Haeckel himself reasoned in regards to this matter, Paul Dombrowski, a specialist in rhetoric, points out in a paper about Haeckel, in an almost euphemistic manner:

> "Though a popular audience can perhaps be forgiven for enjoying to see things as they prefer to see them to seem [*sic*], among careful scientists the more satisfying pleasure is to see things as they are empirically shown to be, and to accept that."[48]

So how, then, would we separate a schematic illustration from a fabrication? One of the reasonably simple criteria is that the illustration must convey *exactly the same message and points* which the original material in nature does, and represent nature as faithfully as possible in that regard. Yet with Haeckel's illustrations, exactly the opposite is true. The altered illustrations support theories which the originals do *not*. So it's not unreasonable to call them fakes or *fraudulent*.

Honest vs dishonest 'mistakes'

Richards admits in his book[4] that Haeckel made a 'mistake' with the triple print of the same woodcut. But not without a twist. He tries to persuade his readers that Haeckel basically only made an *honest* mistake, a mere error in judgement, a mere lapse (pp. 303, 333–334), and that each scientist since yesteryear got certain things wrong (p. 453). Haeckel himself reasoned more or less the same way, that he made a 'mistake' (see pp. 299 and 302).

However, there is a big difference between making *honest* mistakes (which can happen to all human beings) and propagating things *known* to be wrong—in spite of the truth, or contrary to the evidence. To take a simple, hypothetical example: a person accidentally injuring a family member while cleaning a gun (due to negligence or whatever), for example, has made a serious but an *honest* mistake. A man cheating on his wife, or a person deliberately shooting someone in order to murder, are most certainly not making honest mistakes (though their actions can later be seen as 'mistakes' nonetheless if the miscreant is caught and punished). And it is quite amusing to read Haeckel and Richards referring to Wilhelm His and "many other 'exact' pedants" (p. 302). Yet Haeckel was quite exact when it suited him, like with the Radiolarians, for example, as even pointed out by Richards himself!

The previous points in this paper should convince the reader that Haeckel's triple woodcut print is *very* unlikely to be just an honest mistake. And why could Haeckel not have printed the woodcut only once from the very beginning, when referring to the dog, chicken, and turtle? (Even though this would still be problematic, it would be less blatant than the triple printing). No, it seems far more likely that Haeckel pushed his luck in order to argue forcefully for evolutionary theory. And he happened to have (appropriately) burned his fingers.

Conclusion

Although not all of the complaints made against Haeckel during his lifetime may have been valid, the original complaint about Haeckel and his triple printed woodcut in itself certainly *is*. All indications are that Haeckel knew full well what he was doing. Even though we could not treat *every* claim made by Richards, his attempts to salvage Haeckel rest on false premises, ignorance about the good light microscopes of Haeckel's time, as well as ignorance of embryology. Richards is also caught contradicting himself. In this study, old literature was predominantly used for visual comparison of embryos—so the complaint cannot be made that we played Haeckel off against 'modern' knowledge.

It is further noticeable that Richards seems to have mostly only resurrected many of Haeckel's *own* excuses[49] for his triple woodcut print (but also the tailbud stage illustrations treated in Part I) in philosophizing about the 'mistake'—often trying to obscure the obvious. He is thus not a neutral observer commenting on events. Moreover, in writing and philosophizing about this issue, Richards seems to commit the *fallacy of composition*—he reasons and draws conclusions about this episode as if it was something that happened in isolation. However, if we take Haeckel's work and consider the overall picture, the conclusions are different—notably that this is one more of Haeckel's several fabrications. We must ultimately come to the conclusion that Ernst Haeckel was *no honest scientist*, and ultimately deceptive (and maybe even fraudulent) about this matter, too.

Acknowledgements

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11. Richards, ref. 6, p. 153
12. Richards, ref. 4, p. 243
13. Most of the information obtained from: Bradbury, S., The Microscope in Victorian Times; in: *The Microscope Past and Present*, Pergamon Press, chap. 5, 1968.
14. Father of Joseph Lister, 1st Baron Lister, (1827–1912), the pioneer of antiseptic surgery.
15. Co-proposer of the van Cittert–Zernike theorem about distant incoherent light sources.
16. After Friedrich Adolph Nobert (1806–1881), who developed a machine that could rule very fine parallel lines into glass, down to only 0.11 μm, below the limit of the optical microscope.
17. Lustig, A., Richards, R.J. and Ruse, M., *Darwinian Heresies*, Cambridge University Press, 2004. In the essay by Robert J. Richards called, If This Be Heresy: Haeckel's Conversion to Darwinism, pp. 104–105.
18. Richards, ref. 4, p. 27, 29.
19. Richards, ref. 4, p. 30.
20. biology-online.org/dictionary/Leydig_cell, accessed 27 June 2012.
21. Take note, this is not his very first work on them, only the first which made him famous.
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25. Haeckel, E., *The History of Creation, or the development of the Earth and its inhabitants by the action of natural causes: A popular exposition of the doctrine of evolution in general, and that of Darwin, Goethe, and Lamarck in particular,* 4th English edn translated from the 8th German edn by Prof. E. Ray Lankester, D. Appleton & Co. New York, p. 344, 1892.
26. Haeckel, ref. 25, p. 350.
27. Just to be clear that he made this claim in other editions of the book too, we point out that this statement is also found word for word in the 1876 English edn, translated also by Lankester, published by Henry S. King & Co., London, p. 305, 1876.
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30. Oberholzer, G., Van Hamburg, H. and Swanepoel, J.H., *The Early Embryogenesis of Biparental Chordates*, pp. 53–54. This is a set of notes in book form, from which students study embryology at pre-graduate level at a well-known university of South Africa. All three authors are (full) professors at various universities in South Africa.
31. Richardson and Keuck, ref. 10, p. 507. Note, Richards not only references this source, but was actually asked to check this article before publication! So he is truly without excuse!
32. Oberholzer *et al.*, ref. 30, pp. 61–68. A relevant visual illustration is found on p. 64.
33. In the extensive text of: Nelson O.E., *Comparative Embryology of the Vertebrates*, McGraw-Hill, New York, 1953, compare the following diagrams which are relevant: For the lancelet *Amphioxus*, see figure 247 (E), (F), and (G) on p. 501. For the shark *Squalus acanthias*, see figure 229 (A), (B), (C), and (D) on p. 475. For the trout *Salmo fario*, see figure 211 (G) on p. 440. For a common frog (species not given, but likely in the genus *Rana*), see figure 220 (A) on p. 462. For the common Mudpuppy *Necturus maculosus* (which is a salamander), see figure 227 (B), (C), and (D). For a common turtle (species not given), see figure 231 (L), (M), (N), and (O) on p. 479. For a common chick embryo (like that of the genus *Gallus*, which also includes the domestic chicken), see figure 232 (A), (I), and (J) on p. 480, as well as figure 233 (A) and (B) on p. 481. Placental mammals: for the pig, see figure 242 (A), (B), (D), (E), and (F) on p. 496. For a human, see figure 245 (A) on p. 499. It would be good to obtain more pictures of the neurulation process for humans.
34. See again, Nelson, ref. 33, figure 220 (A) on p. 462, as well as figure 219 (A) on p. 460.
35. Keibel, F. (Ed.), *Nomentafeln zur Entwicklungsgeschichte der Wirbelthiere*, vol. 3 (*Ceratodus fosterei*), Verlag von Gustav Fischer, Jena, 1901. Plate I, just after p. 38.
36. Semon, R., *In The Australian Bush And On The Coast Of The Coral Sea*, Macmillan and Co., London, p. 99, 1899. This work also gives a plate of the embryology of the Australian lungfish, though less detailed than the Keibel work in the previous reference. Ironically, Semon was a student of Haeckel's, and he dedicated this book to his master.
37. Keibel, F. (Ed.), *Nomentafeln zur Entwicklungsgeschichte der Wirbelthiere*, vol. 10 (*Lepidosiren paradoxa* & *Protopterus annectens*), Verlag von Gustav Fischer, Jena, 1909. Plates I and II, respectively.
38. Haeckel, E., *The History of Creation*, 4th English edn, translated (from the 8th German edn) by Lankester, E.R., D. Appleton & Co, New York, p. 349, 1892; caption to figure 7. Take note, in the caption itself, Haeckel said that the illustration applied to a mammal or a bird. But in the main text he clearly said that it applied to all vertebrates.
39. Carlson, B.M., *Patten's Foundations of Embryology*, 4th edn, McGraw-Hill, New York, 1981; p. 566—see figure A-24.
40. Brass, A., *Abriss der Zoologie für Studirende, Ärzte und Lehrer*, Wilhelm Engelmann, Leipzig, p. 282, 1882.
41. Hickman *et al.*, ref. 29, p. 857.
42. "Heterochrony" at: dictionary.reference.com/browse/heterochrony, accessed 5 January 2013.
43. Richardson, M.K., Heterochrony and the Phylotypic Period, *Developmental Biology* **172**:412–421, 1995.
44. Hickman *et al.*, ref. 29, pp. 116–117.
45. Richardson and Keuck, ref. 31, p. 504.
46. Richards, ref. 4, p. 299.
47. Gould, S.J., Abscheulich! (Atrocious!), *Natural History* **109**(2), March 2000.
48. Dombrowsky, P., Ernst Haeckel's Controversial Visual Rhetoric, *Technical Communication Quarterly* **12**(3):318, Summer 2003.
49. For example, see what Haeckel wrote in *The Evolution of Man*, vol. I, D. Appleton & Co., New York, pp. xxxiv–xxxvi, 1897: "I, however, consider that diagrams are much more instructive than such [exact, and technically correct] figures, especially in popular scientific works. For each simple diagrammatic figure gives only those essential form-features which it is intended to explain, and omits all those unessential details which in finished, exact figures, generally rather disturb and confuse than instruct and explain." Note, in this English translation, the word "diagrammatic" is used, while in the original German, "schematischen", is used, which Richards correctly translated as "schematic". In regards to leaving out supposedly unessential details, Daniel Davidson, in ref. 5 (p. 50) noticed how Richards reasoned along the same lines: That it was (and is) standard practice to remove peculiar traits and markings of a particular embryo to produce a standardized depiction. However, some of the things Haeckel left out, such as heart bulges, are not unessential at all, and his neurula embryos (as well as his tailbud stage embryos, treated in Part I) are given to the reader for overall comparison. It seems rather that Haeckel conveniently left out features that broke visual similarity.
50. From mk-richardson.com, accessed 14 January 2013.

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