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Kratzenstein's vowel resonators – reflections on a revival

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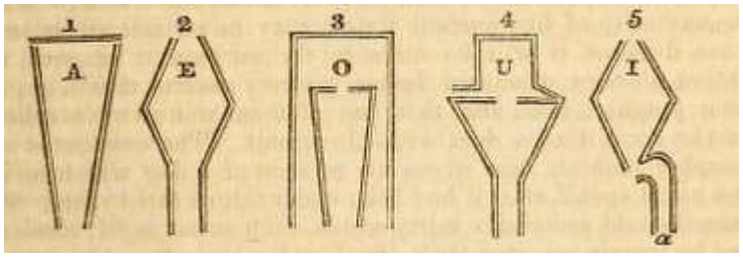
Most commonly, Kratzenstein's phonetic works are discovered by way of the widespread pattern drawings of his resonators in monographs and essays.
The following reproduction is taken from the eighth issue of the popular scientific book *A System of Natural Philosophy* of 1845, which appears to be the origin of the drawings and their later variations.

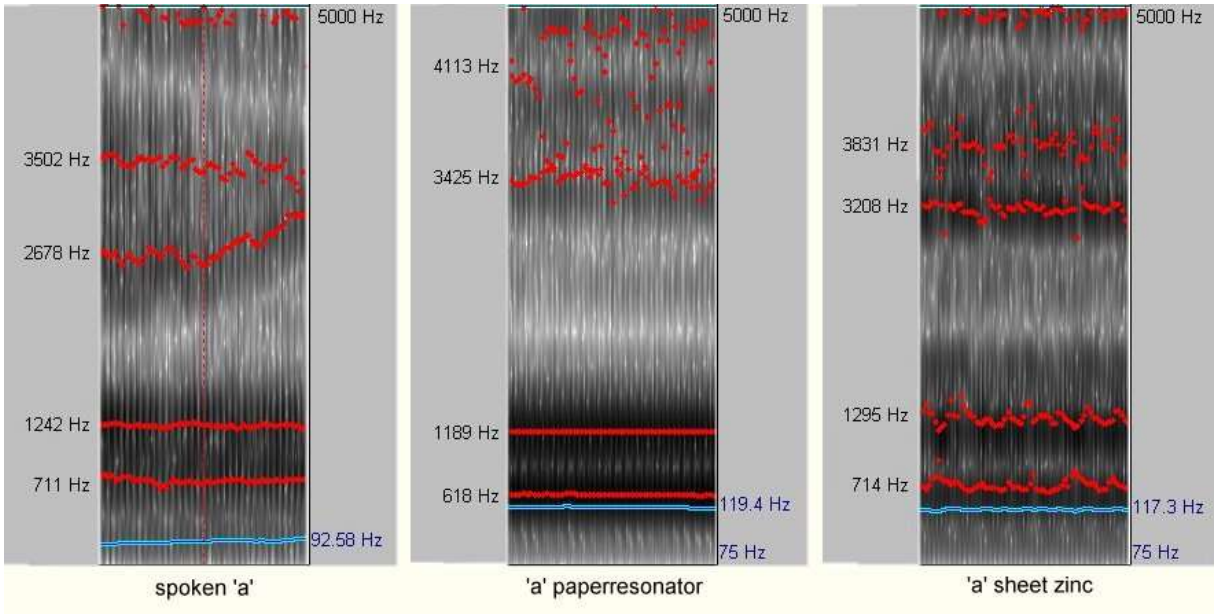


Pattern drawings of the Kratzenstein resonators [1]

They are usually accompanied by terse explanations of the following kind: 'In 1781, Christian Kratzenstein, a German scientist, was awarded a prize at the Saint Petersburg Academy of Arts for his presentation of five resonators that served to produce the five vowels a, e, i, o and u. Shortly afterwards, Wolfgang von Kempelen constructed a speech machine which was able to produce syllables.' This is often followed by the mention of Charles Wheatstone, who reportedly experimented with a reproduction of Kempelen's machine in the first half of the 19th century. These are, in short, the few facts that are commonly disseminated about Kratzenstein and his vowel resonators.

1. Starting practical

On the basis of these rather scant notes I began in 2005 to design resonators from sheet zinc from the above sketches and a comparison with the corresponding sections through the vowel tract. In treatments of the subject 'vowel production' in the course of several lectures on the physiology of language, the accompanying demonstration of the resonators served to



considerably raise the students' interest in phonology. Subsequent measurements with the vowels stimulated by a saw tooth frequency resulted, over and above the subjective hearing impression, in a distribution of the formants that correlated surprisingly well with the spoken vowels. [2]

Set of resonators from sheet zinc

2. Using the 'Tentamen resolvendi problema ab Academia Scientiarum Imperiali Petropolitana ad annum 1780 publice propositum'

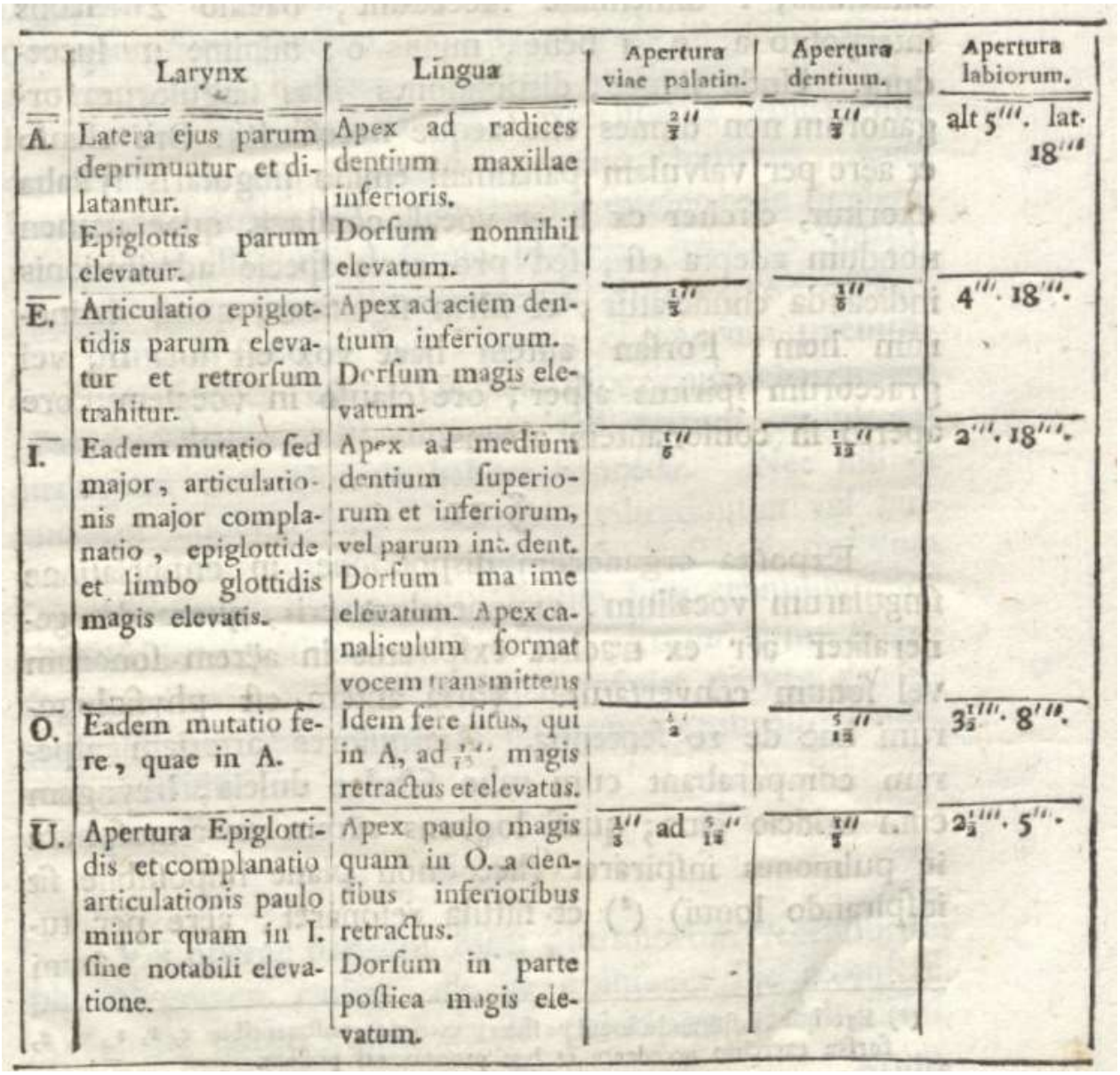
An original copy of the 'Tentamen' became available only in 2008 when Wilfrid Braun, a former colleague, retrieved its location in the collection of the Goettingen State and University Library. I then arranged its digitization – including the plates – in order to make the text available on the Internet.

A first reading of the 'Tentamen', especially of §§ 9. and 10. gives the impression that it was written to provide directions for the construction of resonators. In § 9. Kratzenstein assembles a list specifying the aperture dimensions of the vowel tract. These had been determined with the aid of a flat chip of wood which was put upright between the teeth or lips; for particular widths it could then be ascertained which vowels could be correctly articulated by observing the corresponding opening.[3] Kratzenstein points out that these measures are neither exact nor observable simultaneously.[4] In the same context we also find an early mention of the fact that the vowels are involuntarily pronounced with an initial consonant.

The data probably originate from previous works by Kratzenstein, in which he had occupied himself with phonetic as well as anatomical features of the vowels some time before the prize question.[5] In paragraphs 11 to 24 he deals with Denis Dodard and Antoine Ferrein as well as with the advancement of their theses by Albrecht von Haller [6] in order to develop a view of the production of the vowels from a physician's point of view.

Section 2 of the 'Tentamen' is headlined: 'De construendis fistulis, vocales a, e, i, o, u enunciantibus' (about the construction of pipe-whistles which express the vowels a, e, i, o, and u). To begin with, it must be stressed that Kratzenstein did not conceive of the construction of the vowel resonators as an imitation of the vowel tract. Instead, he developed the forms by extensive experiments. It is not surprising that these basically reproduce form principles of the vowel tract, as we will see in the case of 'e'. Their measures, however, are derived acoustically from the sizing of the 'e' to correspond to the tone C' (at that time 247

hertz). For the height of a cone Kratzenstein indicates a length of about 3 ‘thumbs’[7] (foot/12). Sections 26 to 30 describe in more or less detail the construction of the resonance bodies prepared for the vowels. [8] This is supplemented by the original drawings displayed in the appendix.



	Larynx	Lingua	Apertura viae palatin.	Apertura dentium.	Apertura labiorum.
A.	Latera ejus parum deprimuntur et dilatantur. Epiglottis parum elevatur.	Apex ad radices dentium maxillae inferioris. Dorsum nonnihil elevatum.	$\frac{2}{3}''$	$\frac{1}{3}''$	alt $5'''$. lat. $18'''$
E.	Articulatio epiglottidis parum elevatur et retrorsum trahitur.	Apex ad aciem dentium inferiorum. Dorsum magis elevatum.	$\frac{1}{3}''$	$\frac{1}{6}''$	$4'''$. $18'''$.
I.	Eadem mutatio sed major, articulationis major complanatio, epiglottide et limbo glottidis magis elevatis.	Apex ad medium dentium superiorum et inferiorum, vel parum int. dent. Dorsum ma ime elevatum. Apex canaliculum format vocem transmittens	$\frac{1}{6}''$	$\frac{1}{12}''$	$2'''$. $18'''$.
O.	Eadem mutatio fere, quae in A.	Idem fere situs, qui in A, ad $\frac{1}{15}''$ magis retractus et elevatus.	$\frac{1}{2}''$	$\frac{5}{12}''$	$3\frac{1}{2}'''$. $8'''$.
U.	Apertura Epiglottidis et complanatio articulationis paulo minor quam in I. sine notabili elevatione.	Apex paulo magis quam in O. a dentibus inferioribus retractus. Dorsum in parte postica magis elevatum.	$\frac{1}{3}''$ ad $\frac{5}{12}''$	$\frac{1}{5}''$	$2\frac{1}{2}'''$. $5'''$.

Opening measures of the vowel tract [9]

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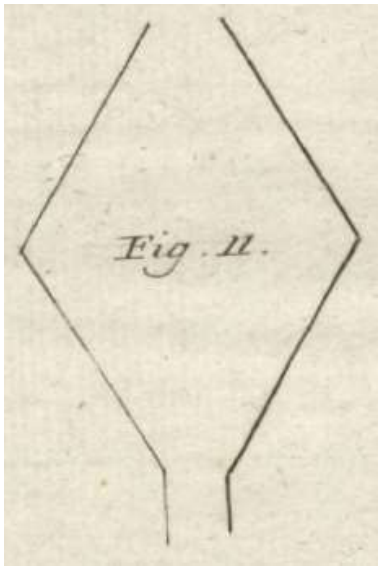
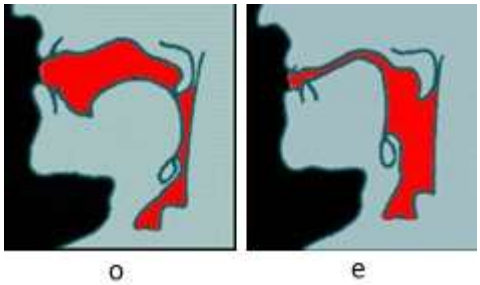


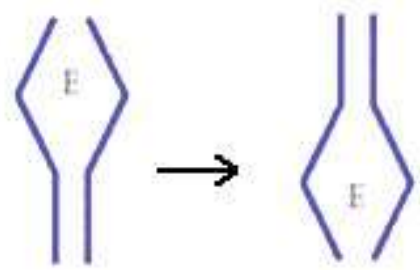
Thanks to the alertness of Rüdiger Hoffmann, the reappraisal of Kratzenstein's work including its practical results – the reconstructed instruments – have found a place in Dresden as part of the ‘Historische Akustisch-Phonetische Sammlung’ (historical acoustic-phonetic collection); this is all the more to be appreciated, since the web page containing my detailed documentation was moved to a somewhat isolated position after my retirement from teaching at the university in 2008.

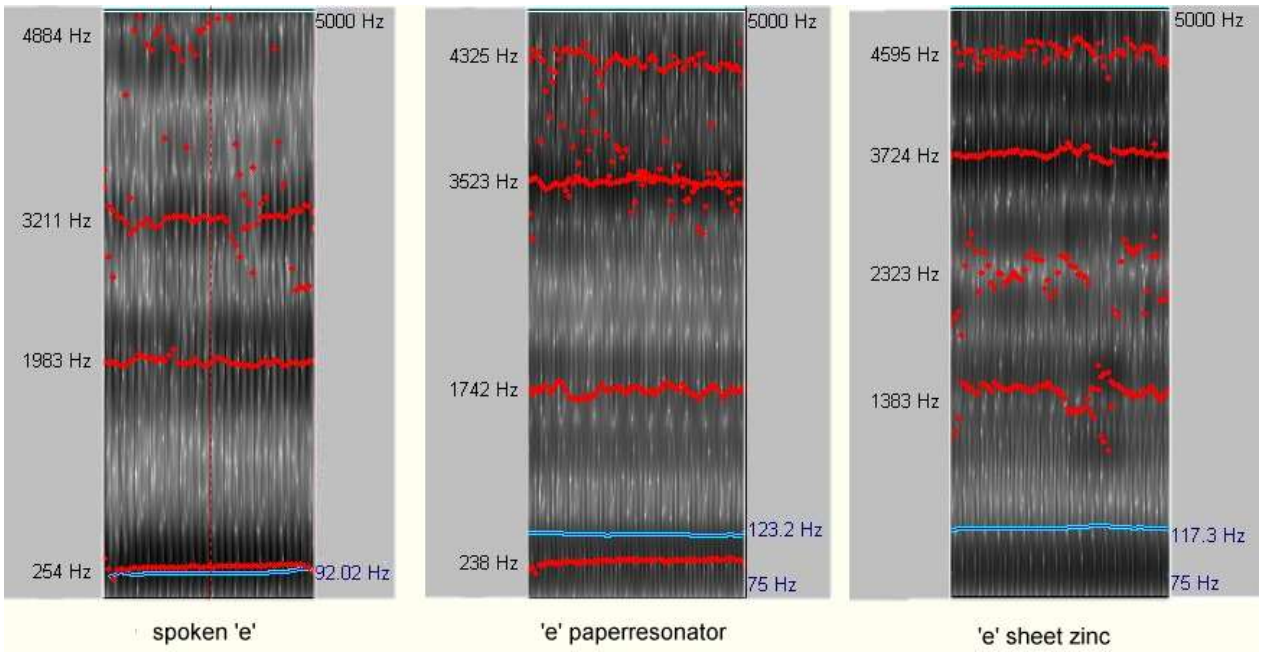
3. Correcting the drawings

It is advisable not only to view the drawings but to read the descriptions that go with it. The construction of the ‘e’ is shown in Fig. 11 as well as in the drawing. The explication reads thus: ‘On the upper cut-off part sits a tube stub that is wide enough for a little finger to be inserted into it. [16]
As early as 2007 I presumed this to be the correct adjustment as opposed to Fig 11.[17] When the resonator was operated as indicated by the drawing, the audible result was clearly indifferent in comparison to the others. This could be confirmed by measurements: the formants did not resemble those of an ‘e’ at all. Setting the resonance body against the schematic cuts of the vowel tract indicated the mistake.



If the ‘o’ is considered as a two tube resonator, the upper one is narrow, while the lower one is clearly broader in comparison. In the case of ‘e’ the relations are exactly reversed. The mere fact advocates – without reference to the ‘Tentamen’ – a change in the design of the resonator as shown in the pattern drawing: The acoustic impression as well as the measurement of the formants then produce satisfactory results.

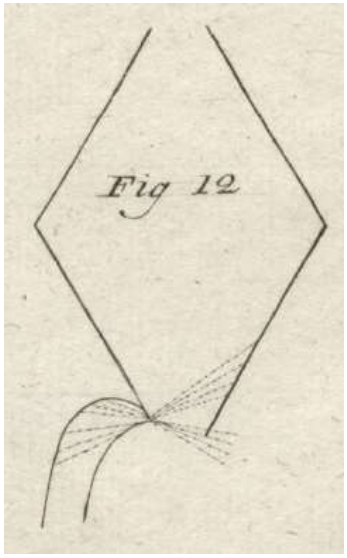




4. The i-Problem

In generating the ‘i’, too, the drawing alone (Fig. 12) is not really helpful. Even though the patterns characterizing the silhouette seem to be largely correct, no vowel resembling an ‘i’ can be generated with a resonator whose shape follows the pattern. Kratzenstein himself must have been aware of this problem: His article devoted to the ‘i’ is by far the longest.

As regards the acoustic excitation of the resonators, their description in ‘A System of Natural Philosophy’, mentioned at the beginning, contains the following explanation: ‘[Kratzenstein] showed that the sounds of the four vowels, A, E, O, and U, might be obtained by blowing through a reed into several tubes, the forms of which are represented in the annexed figures 1, 2, 3, and 4; and that the sound of I, as pronounced by the French and other continental nations was produced by blowing at a, into the pipe No. 5, without using a reed.‘ [18] The only



twentieth century author who appears to have taken notice of it is George A. Miller; he comments it as follows: ‘The resonator for i was blown about the opening, the other resonators were activated by introducing a vibrating pipe sheet’. [19]
This explanation, however, is no more than a hint at what the dotted lines to be found in the original drawing (bottom end) can be supposed to signify. Their interpretation is complicated by the incorrect representation of the airstream, for a hollow body blown in this manner – for example a bottle – would be blown above the right edge.
The description in the text explains the underlying principle more clearly: ‘Near to this pipe a resonator made out of two truncated cones, as we know them for the vowel ‘e’, is attached in such a way that the airstream blows at the resonator as is the case with a transverse flute.’ [20]
This explanation is a double statement: It points out a method of how to handle this resonator successfully, in contrast to the others. In addition, it intimates that, judged by its construction and functionality from a systematic point of view, the appliance does not, in fact, qualify as a ‘resonator’. Kratzenstein is conscious of this and states the reason why his construction lies beyond the scope of the system: ‘With regard to this vowel, however, a gap would be left open in our work, and thus I have developed a different kind of flute pipe which generates this vowel with sufficient clarity’[21] While all the other vowel resonators are to be considered bells of reed pipes, Kratzenstein here constructs a labial pipe. Strictly speaking, it cannot, therefore, correctly be called a resonator. Rather, it is a pipe body whose length generates the audible oscillation stimulated by the lip.
All vowel producers were stimulated aerodynamically; this is equally valid for the tongue lamella of a pipe whistle with resonator and the edge of a labial pipe. Until the vibrating air column stands, one hears the stimulating airflow. Hence, Kratzenstein always observes the occurrence of an initial sound ‘h’ in natural articulation as well as in operating his vowel-tubes. [22]
Aerodynamic processes are left unconsidered in the source-filter model, which is expounded in every phonetics textbook in order to explain the production of vowels. Technically speaking, though, it disregards the same difficulty that Kratzenstein explicated in his work on vowels. In order to close this gap, to my mind a solution should be sought by extending the explication of the vowel production beyond the source-filter theory. Nowhere, however, is such an approach to be found. It would be of interest to work out – at least from a history of science angle – the point in time when investigations in the aerodynamic processes of the vowel production ceased. The electromechanical treatment of the problem, originating in the 19th century, was able to cope without resorting to aerodynamics. I believe, however, this latter field still matters – for the history of science as well as for purposes of vocal education and speech therapy.

5. History of Sciences, practical utility and profit

A reassessment of Kratzenstein’s achievements raises a further question, that exceeds the technical aspects of his works. I will outline it briefly. It concerns the applicability of scientific findings and their role in promoting the natural sciences in the eighteenth century.
His invention of a reed pipe with a free reed took up a disproportionate space in subsequent descriptions, and its advantages were praised exceedingly. This was followed by a heated

discussion about its authorship in the instrument making craft. For some time, Leonhard Euler had corresponded with Kratzenstein concerning acoustic problems and, as his acquaintance, presumable brought his authority to bear when it came to drawing up the 1780 prize question of the academy. Only two years later, the audience at Kratzenstein's 'lectures on experimental physics' were deeply impressed by his extensive scientific knowledge of phenomena and theories.[23] In 1783, the first manned flight of the 'Montgolfière' was launched, and Kratzenstein quickly responded by publishing his work. 'L'Art de naviguer dans l'Air' in the following year. It contains extensive instructions for the calculation of the size and load-carrying capacity of hot-air balloons of this type as well as deliberations on their scientific and commercial uses. [24] Kratzenstein has been described as a very modest person while being generous towards his employees. This assessment allows us to conclude that he indeed possessed an entrepreneurial mind that was also guided by prospects of income to be achieved by the application of his research.

The origins of modern natural science and the organization of the scientific community are to be sought in the eighteenth century; the impetus of its development is unabated to the present day. It is marked, in the first place, by an increasing systematization of practical knowledge that is further fueled by international exchange. The Petersburg Academy liberally offered free correspondence and publication, which made it extremely attractive for its members. [25] Concurrently, scientific work became increasingly independent of its immediate practical utility, which can be documented by an extensive list of distinct stages characterizing this progress. These practices were taken up by Wilhelm von Humboldt, who incorporated them into a university concept based on his humanistic educational theory.

On closer examination of the historical facts underlying this development, however, the absence of an overall picture becomes obvious. How did the financing and organization of scientific work change up to the status that it reached at the end of the nineteenth century, for example in Germany? When and where and from what motives was this change brought about? It was at this juncture that technical education was integrated into the university system and its working methods. The history of the Dresden University of Technology vividly bears witness to it. It might be rewarding to investigate the development from Kratzenstein's time to the second half of the nineteenth century, in order to critically assess the formation of a corresponding theory.

Its absence is regrettable, the more so as at present we appear to revert to its beginnings – by deeming as progressive the notion that education and research are essentially to be counted as investments.

References

Acknowledgements: Thanks to my colleagues Wilfried Braun and Frederik Heinemann this essay got its English version.

[1] A System of Natural Philosophy. Philadelphia 1845, p. 265. Thanks to Rüdiger Hoffmann for referring me to this title.

[2] Korpiun, Christian: 'Kratzenstein wiederbelebt'. 2015. Glottis und Schallquelle in http://www.seam-uni-essen.de/physiologie/akustik/resonatoren/uebersicht_sprechakustik.htm

[3] Kratzenstein, Christian T: 'Tentamen resolvendi problema ab Academia Scientiarum Imperiali Petropolitana ad annum 1780 publice propositum'. Petersburg 1781. §10, p. 16. http://resolver.sub.uni-goettingen.de/purl?PPN59586435X

[4] loc. cit.

[5] Tentamen §§2–8.

[6] Albrecht von Haller: Anfangsgründe der Phisiologie des menschlichen Körpers. Berlin 1766. pp. 695 ff.
http://www.deutschestextarchiv.de/book/view/haller_anfangsgruende02_1762?p=7

[7] Tentamen §27, p. 39f.

[8] Korpiun op. cit., ‘Kratzenstein wird geadelt’.

[9] Tentamen §9, p. 15.

[10] Tentamen, §10, p. 16

[11] loc. cit.

[12] Tentamen §§2–8.

[13] von Haller, Albrecht 1766 pp. 695 ff.

[14] Tentamen §27, p. 39f.

[15] Korpiun op. cit., ‘Kratzenstein wird geadelt’.

[16] Tentamen §27, p. 39f.

[17] Korpiun op. cit. ‘Das Problem mit dem ‘e’’.

[18] loc. cit.

[19] Miller, George A.: Wörter. Streifzüge durch die Psycholinguistik Heidelberg, Berlin, New York 1992, p. 88

[20] Tentamen §28, p. 41f.

[21] Tentamen §28 p. 41.

[22] Tentamen §8, p. 14.

[23] Kratzenstein, Christian T: Vorlesungen über die Experimentalphysik. Kopenhagen 1781. http://reader.digitale-sammlungen.de/resolve/display/bsb10131365.html

[24] Kratzenstein, Christian T : L’art de naviguer dans l’air. Kopenhagen und Leipzig 1784. http://reader.digitale-sammlungen.de/resolve/display/bsb10080962.html

[25] Kopelevič, Judith K.H.: Euler und die Petersburger Akademie der Wissenschaften. pp. 378f. In: Fellmann, E.A. (Hrsg.): Leonhard Euler 1707–1783. Berlin 2013. pp. 373–382. http://link.springer.com/chapter/10.1007%2F978-3-0348-9350-3_19#page-1