When Rational Frameworks Meet:

Natural Philosophers and Artisanal Knowledge in the Early Nineteenth Century

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This essay addresses what happens when different rational frameworks meet face to face. Specifically, I wish to use Menachem Fisch and Yitzhak Benbaji’s modification of Peter Galison’s concept of a trading zone in order to analyze two episodes in the history of science.[[1]](#endnote-1) The first deals with John Herschel’s attempt to assist his nation in constructing optical lenses, which could rival that produced by the Bavarian optician, Joseph von Fraunhofer. The story that unfolds is one in which an experimental natural philosopher engaged with someone from a community often related to, yet very much distinct, from his own, namely scientific instrument makers. Knowledge, skills (albeit less efficiently), and artifacts were often exchanged between these two groups, in a way reminiscent of Galison’s notion of a trading zone. As Fisch correctly points out, trading zones are sites of instability where one’s worldview can easily be challenged and even undermined.[[2]](#endnote-2) Outsiders often destabilize taken-for-granted commitments and beliefs, which are so critical to the scientific enterprise. This was the case with John Herschel, who claimed that nothing less than his view of science was jeopardized by the British inability to produce Fraunhoferian-quality achromatic lenses.

Key to understanding Herschel’s response to Fraunhofer, and the Englishman’s commitment to the universal applicability of “scientific art”, as he called it, is to “carefully review the actor’s circumstances, values, and assets, and goals, with a view to assessing the aptness of her [his] response to the specific task at hand.”[[3]](#endnote-3) Herschel went to the glass hut in Benediktebeuern committed to the openness of science, a cornerstone to his rational framework. His rational framework was challenged first by Fraunhofer’s commitment to secrecy and second by the inability of the British to reverse engineer the Bavarian’s achromatic glass.

Fraunhofer’s rational framework was quite different. He was obliged to practice secrecy, since he and his employer, director of the Optical Institute Joseph von Utzschenider, felt that Herschel could in principle glean information that would result in the usurpation of the optical market. Contra Herschel, both Fraunhofer and Utzschneider reckoned, correctly as it turns out, that potential competitors could not reverse-engineer the lenses without witnessing the labor practices involved in achromatic glassmaking. Hence such techniques were enviously guarded from visitors. In this respect, Galison’s notion of a trading zone applies, since “the trading zone must be made safe by ensuring that negotiations are limited to what each side seeks to purchase from the other while cordoning off the broader cultural and other issues that sorely divide them.”[[4]](#endnote-4) Unfortunately, Herschel never changed his rational framework: he continued to underscore the importance of openness to science despite his interaction with Fraunhofer, and he still held firm to the universality of both scientific knowledge and its application. Similarly, Fraunhofer continued to practice his secrecy until his premature death in 1826, thereby threatening the Optical Institute’s market hegemony, even though such action thwarted his attempts to garner scientific recognition.

The second episode focuses on Wilhelm Eduard Weber’s collaboration with skilled artisans while conducting his research on acoustics. He turned to mechanicians for devices, which he used in his work on adiabatic phenomena and the standardization of musical and physical phenomena. Unlike the first episode, however, knowledge flowed freely between the experimental natural philosopher’s and artisans’ rational frameworks, to the benefit of both parties. Skilled artisans were rewarded financially for their labor. And organ builders welcomed Weber’s work on compensa ted reed pipes, as it enabled them to produce such pipes more efficiently. Weber clearly possessed a rational framework, which was predicated upon openly trading with artisans. Since his collaborations were successful, there was no need from him to alter his rational framework. In this case, one is reminded of Fisch and Benbaji’s point that “when ‘trading’ abroad one is frequently exposed to the friendly and trustedly [sic] bemused questioning of genuinely curious professionals, on whose thinking the framework constitutive of one’s own may have far less of a grip.”[[5]](#endnote-5)

**John Herschel**[[6]](#endnote-6)

John Frederick William Herschel was the only child of the renowned astronomer, Sir William. He was raised in upper-middle-class household in Slough where he often and polished optical lenses for use by his father. At age 17 he matriculated at St. John’s College, Cambridge, studying mathematics. While at Cambridge he befriended Charles Babbage, George Peacock, and William Whewell, all of whom would greatly influence British natural philosophy later in that century. They co-founded the Analytical Society, which attempted to bring the advanced methods of mathematical analysis practiced on the Continent to the British curriculum. Herschel sat the tripos examination in 1813 and was named Senior Wrangler. Immediately thereafter he was elected to a fellowship at both St. John’s College and the Royal Society. In 1816 he left Cambridge to embark on a scientific career.

After working in mathematics, Herschel turned his attention to physical and geometrical optics, studying the polarization of crystals, the interference of light and sound waves, and the solar system. His first contribution to astronomy (1822) dealt with the computation of lunar occultations. He and James South catalogued 380 double stars in 1824, for which they received the Laland Prize of the French Academy in 1825 and the gold medal of the Astronomical Society in 1826.

Herschel became familiar with the standard of optical glass produced in Benediktbeuern, Bavaria in 1821 when M. Reynier, an assistant of Pierre Louis Guinand- Fraunhofer’s mentor, informed the Astronomical Society that Guinand could manufacture flint glass free of bubbles and striae.[[7]](#endnote-7) M. Reynier sent several of Guinand’s flint glass disks from his home in Les Brenets, Switzerland, to London, where Herschel, Davies Gilbert, and William Pearson were asked to judge them.[[8]](#endnote-8)

The differences between British and Bavarian glassmaking traditions became most profound when Herschel attempted to gather information from Fraunhofer on achromatic-lens production on behalf of the Board of Longitude and the Royal Society’s Joint Committee for the Improvement of Glass for Optical Purposes. In Benediktbeuern, the two traditions and cultures met face to face. During September of 1824, Herschel traveled to the Continent, where he met up with Fraunhofer on 19 September, in order to obtain information on the Bavarian’s method of optical glass manufacture for the Joint Committee. Herschel, upon being greeted in the former cloister at Benediktbeuern, wrote to his good friend Charles Babbage: “I saw Frauenhofer [sic] & all his works but the one most desirable to see: his glass-house, which he keeps enveloped in thick darkness.”[[9]](#endnote-9) Clearly, Herschel thought that witnessing Fraunhofer’s workmanship would be the most effective way to glean information on the production of optical glass. Fraunhofer- lest he give a potential competitor too much insight- would not permit Herschel to witness the labor practices involved in glass manufacturing, or even the inner structure of the glass hut. Fraunhofer did, however, personally demonstrate to Herschel how he produced the dark lines in the spectrum and how those lines could be used as a system of calibration for achromatic lenses.[[10]](#endnote-10) He revealed nothing else. Herschel was amazed. He continued his letter to Babbage: “One thing is certain, he [Fraunhofer] has completely resolved the problem of making perfect flint glass, homogenous.”[[11]](#endnote-11) He praised Fraunhofer once, again, this time to Joseph Johann Littrow, the professor of astronomy in Ofen, on 9 November 1824:

I passed some time at Munich with M. Frauenhofer [sic] with whom I was much delighted. I will not say that I think his results merely interesting, they are admirable & instinctive. He is the only optician existing I believe who has aimed at applying strict theory to exact data in the construction of his glasses. It is a pity he makes a secret of his glass-making & it were to be wished that he would publish the math. theory and numerical computation of the curvatures of his large achromatics. [Underlining in the original][[12]](#endnote-12)

Herschel was hinting here that Fraunhofer’s mathematics, optical theory, and calculations would enable him to reproduce Fraunhoferian lenses. As discussed below, secrecy was antithetical to Herschel’s rational framework.

Although he was rather disappointed, Herschel certainly did not despair when he found that Fraunhofer would show him neither the skilled labor involved nor the pieces of glass in different stages of the process, only the finished products.[[13]](#endnote-13) Herschel was initially optimistic that the British could ferret out the secrets by using scientific methods. The polymath and inventor Henry Fox Talbot continued to provide Herschel with lenses from the Optical Institute after Fraunhofer’s death in 1826, and Herschel received other samples from the Optical Institute a year later. He wrote to the chemist Michael Faraday, a member of the subcommittee, on 27 August 1827: “I have just got some prisms from Utzschneider’s manufactory among which is a large one of flint glass of the utmost perfection being like a piece of solidified water without a trace of a vein or imperfection of any kind. This shews … that the problem is capable of being resolved.”[[14]](#endnote-14) The resolvable problem to which Herschel was referring was the attempt of the British Joint Committee to produce flint glass as homogeneous as Fraunhofer’s. This would suggest that Herschel did not believe that Fraunhofer’s personal and practical knowledge was necessary, since superb glass was being produced after Fraunhofer’s death. Hence, for Herschel the labor processes were not dependent upon Fraunhofer. Herschel also seemed to think that Fraunhofer’s prisms could be replicated by the subcommittee without any knowledge of the skilled-labor practices used in Bavaria to produce optical glass, although he certainly never claimed it would be easy or straightforward.

Herschel’s trip to Benediktbeuern must also be put into its proper context. He was the leader of scientific reform in Britain in the 1820s and 1830s. Philosophical reasoning, experimental science, and economic science were, in Herschel’s eyes, all interrelated. His insistence that scientific and mathematical knowledge was indeed communicable is not surprising; after all, that is precisely what a Senior Wrangler did: communicate complex technical knowledge. Hence, it now becomes clear why Herschel would claim that if only Fraunhofer would publish his mathematical theory and calculations, he might be able to construct similar lenses and prisms. Herschel’s wish to see “the math. theory and numerical computation” is striking since it implies, once again, that artifacts could be reproduced by using mathematical theory where secrecy hid the manual technique. Mathematics was, in his eyes, universally communicable. When Herschel described the criteria of good flint glass for the subcommittee, which was established by the Joint Committee at the urging of Herschel, to imitate, he claimed that they were very desirable, as they

permit the very ready & simple application of an exact mathematical theory to the construction of object glasses without supposing any knowledge of mathematics in the artist beyond the working [of] object glasses from exact measures of their refractive & dispersive powers, and a computation thereon founded on the proper radii to destroy aberrations and till this practice in general [is known,] it is vain to expect perfect glasses, even with good materials.[[15]](#endnote-15)

In Herschel’s eyes, the general principles of mathematics, in addition to superior optical glass, were required to reproduce Fraunhoferian lenses. Herschel never seemed to appreciate the difficulty of creating optical glass.

After his meeting with Fraunhofer in September in 1824, Herschel praised the Bavarian’s experimental technology of using the dark lines in the spectrum as a method of calibrating lenses.[[16]](#endnote-16) Herschel was concerned that British optical hegemony was in serious jeopardy:

I have seen such specimens of … Frauenhofer’s [sic] workmanship, as has completely cured me of the weakness of national vanity on the point of the higher departments of astronomical instrument making. A school of artists [craftsmen] who have worked with them is gradually rising in various parts of Europe, and without some great effort, British art will no longer hold the prominence it has done.[[17]](#endnote-17)

Herschel continued by emphasizing that Fraunhofer “make a great mystery” of his work, specifically citing Fraunhofer’s glass. He spoke of Fraunhofer’s glass as “faultless,” describing one of the prisms as “of large refracting angle, covering the whole aperture of an object glass 4 inches in diameter and giving spectra of the stars pure enough to see the dark fixed lines which cross them. It is indeed as liquefied as the purest water, being absolutely free from veins or inequalities or refraction.”[[18]](#endnote-18)

Herschel used the glass crisis to legitimize his own agenda for reform of the Royal Society, but by 1827 he was beginning to realize how difficult that would be. In December he resigned his post as secretary of the Royal Society. After that date, his interest in the subcommittee’s glass enterprise waned considerably. Most important, the Fraunhofer episode illustrates Herschel’s attitude toward skill artisans. He claimed that the production of lenses could be improved by the tradition of rational and scientific knowledge if opticians and instrument makers were to follow the cue of experimental natural philosophers, who in turn were to render their theories accessible to artisans.

In a telling letter to Herschel, Robert Fot, a wright and turner who was studying optics at a school of arts patronized by Herschel, expressed regret that, rather than learning the practical skills of the optical trade, such as optical glass production, he was taught Herschel’s geometrical optics.

You in you neighbourhood patronised a school of arts which instance of condescension to the people of the working class, to which I belong emboldened me to solicit the privelege [sic] of communicating at times with you. I have not been bred an optician, being by profession a wright and turner, but the whole of my leisure is devoted to the study of optics in so far as the construction of achromatic telescopes are concerned. In all the object glasses I have made, your most valuable formula has always been used…. However when after all my pains I fail in making a good one I can manage to better it by a method of polishing anew one side of the Crown lens. But there is one great difficulty continually in my way. I can by no means procure good glass, especially flint.[[19]](#endnote-19)

This letter reflects the general inadequacy of the schools of arts and the Mechanics’ Institutes throughout Great Britain. Rather than teach mechanicians and artisans the application of their trade to the various forms of manufacture, lecturers provided them with information that was not always relevant or helpful.[[20]](#endnote-20) This sentiment was echoed in a letter, which was published in *The Mechanics Weekly Journal* in December of 1823, from a disappointed mechanic.

Scientific lecturers attend to generalities only, and omit the details of practice, with which indeed they are unacquainted. Of course, their lectures (unless rendered unintelligible by the use of philosophical slang, understood only by those who have studied it,) do indeed amuse the hearers, by exhibiting the causes of the effects observable in the operations of the workshops; but they do not directly contribute to the improvement of the traders dependent upon those principles. This improvement can only be made by those who are practically conversant in the minutest details,- who have acquired, by continual practice, that slight of hand which is so essential to a true performance of any mechanical operation, and who are well acquainted with the difficulties and defects which are to be got over. … A large society of this kind [The London Mechanics’ Institute] is likely to hire lecturers high in scientific renown, but little acquainted with the application of their knowledge to the arts of life, or the real practice of the workshop, or the commercial laboratory. So that, while their extended views gratify the highly educated few, the operative mechanic, who is drawn in by fair promises to subscribe his mite to their support, finds his object neglected, sinks at the continual mistakes in minute points, of the learned professor,- withdraws in disgust, and the institution is diverted from its original purpose.[[21]](#endnote-21)

Herschel strongly upheld the notion of the universality, rather than an enculturated model, of scientific skill. His *Preliminary Discourse on the Study of Natural Philosophy* of 1830 reveals his belief in the universality of the scientific enterprise: “It is not one of the least advantages of these pursuits [the study of natural science], … that they are altogether independent of external circumstances.”[[22]](#endnote-22) He continues by extending the notion of the universality of natural science to the universality of knowledge in general:

It [knowledge] acquires not, perhaps a greater certainty, but at least a confirmed authority and a probable duration, by universal assent. … Those who admire and love knowledge for its own sake ought to wish to see its elements made accessible to all, were it only that they may be the more thoroughly examined into, and more effectually developed in their consequences, and receives that ductility and plastic quality which the pressure of minds of all descriptions, constantly moulding them to their purposes, can alone bestow. *But to this end it is necessary that it should be divested, as far as possible, of artificial difficulties, and stripped of all such technicalities as tend to place it in the light of a craft and a mystery, inaccessible without a kind of apprenticeship*. … Everything that tends to clothe it [science] in a strange and repulsive garb … assumes an unnecessary guise of profundity and obscurity.[[23]](#endnote-23)

He stated that practical mechanics, or the domain of knowledge that instructs natural philosophers on how to combine and apply nature’s forces for human purposes, belonged to the domain of purely theoretical knowledge:

Practical Mechanics is, in the most pre-eminent sense, a scientific art; and it may be truly asserted, that almost all the great combinations of modern mechanism, and many of its refinements and nicer improvements, are creations of pure intellect, grounding its exertion upon a moderate number of very elementary propositions in theoretical mechanics and geometry.[[24]](#endnote-24)

Finally, he criticized “empirical art” since it tended toward incommunicable knowledge. Science, by Herschel’s definition, was communicable either by the experimental natural philosophers themselves or by their artifacts. Scientific art, unlike empirical art, made the technical mystery accessible to all cultures.

They [the arts, such as practical mechanics] cannot be perfected till their whole processes are laid open, and their language simplified and rendered universally intelligible. Art is the application of knowledge to a practical end. If the knowledge be merely accumulated experience, the art is empirical; but if it be experience reasoned upon and brought under general principles, it assumes a higher character, and becomes a *scientific* art. … The whole tendency of empirical art, is to bury itself in technicalities, and to place its pride in particular short cuts and mysteries known only to adepts; to surprise and astonish by results, but conceal processes. The character of science is the direct contrary. It delights to lay itself open to enquiry; and is not satisfied with its conclusions, till it can make the road to them broad and beaten: and in its applications it preserves the same character; its whole aim being to strip away all technical mystery, to illuminate every dark recess, and to gain free access to all processes, with a view to improve them on rational principles. It would seem that a union of two qualities almost opposite to each other- a going forth of the thoughts in two directions, and a sudden transfer of ideas from a remote station in one to an equally distant one in the other- is required to start the first idea of *applying* science.[[25]](#endnote-25)

Herschel was disappointed by Fraunhofer’s secrecy, which he claimed was anathema to the character of science. Although secrets and craft knowledge are two distinct entities, they were very initimately related during the early nineteenth century. Herschel called for an opening of artisanal secrets on the ground that they could not be easily deduced by abstract science. But Fraunhofer, according to Herschel, must have practiced scientific art; after all, Herschel awarded Fraunhofer an associate membership in the Astronomical Society of London in 1825, and he labeled the Bavarian both an artist and a philosopher.[[26]](#endnote-26) Hence, he thought he could learn Fraunhofer’s procedures for glassmaking during his visit in 1824. Failing that, he thought that Faraday would be able to recover the procedures by reverse engineering the final product. The transfer of technology from Benediktbeuern to London is precisely what Herschel meant by “applying science.” But by 1827, after two years of failing to replicate Farunhoferian glass, Herschel began to despair. In his minutes of the General Scientific Committee he claimed that “the character of science is itself in some degree at stake” should the subcommittee fail at this venture.[[27]](#endnote-27) The subcommitee, in Herschel’s view, needed to succeed; otherwise his implication that the specific techniques are irrelevant, that generic techniques can be obtained by applying general principles, would be undermined. This was Herschel’s definition of “the character of science.” His belief in the universality of science is also evident from his belief that the rise of new journals throughout Europe placed “observers of all countries on the same level of perfect intimacy with each other’s objects and methods” and “serve to direct the course of general observation, as well as to hold out, in the most conspicuous manner, models for emulative imitation.”[[28]](#endnote-28)

Herschel was attracted to Fraunhofer’s work because of the precision measurements that the Bavarian’s instruments produced. In his *Preliminary Discourse* he noted the importance of improved observation by means of instruments adapted for exact measurement: “What an important influence may be exercised over the progress of a single branch of science by the invention of a ready and convenient mode of executing a definite measurement.”[[29]](#endnote-29) He saw clandestine work as impeding the progress of science.

Herschel and (to a much greater extent) Charles Babbage belonged to a tradition, then nearly 100 years old, which criticized craft knowledge for its secrecy. Denis Diderot, the editor of the *Encyclopédie*, espoused such a belief in Enlightenment France. He wished to free the mechanical arts from the “ignorance and deception” of laborers by opening up craft knowledge. Although he argued both for the importance of artisanal labor and the inability of theoretical knowledge to explain craft processes, Diderot abhorred artisanal corporations, because their secrecy thwarted innovation as well as attempts by scientific knowledge to penetrate and explain artisanal practices. Once these labor processes were revealed, Diderot argued, they could be properly guided by enlightened managers.[[30]](#endnote-30) Babbage himself spent more than twenty years having skilled artisans attempt to build his difference engine, which (rather ironically) was meant to replace the labor of human calculators.[[31]](#endnote-31) One of the models for his intelligent calculating engine was Jean Jacquard’s weaving looms, which were spreading through Paris during the first decade of the nineteenth century. Although Herschel was not quite as extreme as Babbage, he did not think that artisanal knowledge could itself be compared in character to natural philosophical knowledge, and he reckoned that the rational principles of optics and mechanics could suffice for the production of artifacts such as lenses and prisms.

In short, John Herschel’s encounter with Fraunhofer at Benediktbeuern clearly challenged the Englishman’s view of science in general and the communicability of scientific knowledge in particular. There is, however, no evidence that he later changed his view as a result of his meeting the Bavarian optician. Indeed, it is interesting to note that this views on the universal applicability of the rational principles of mechanics and scientific art were published three years *after* his interest in the subcommittee waned considerably. Secrecy was his bugbear: it thwarted the spread of scientific knowledge and economic progress. His hope that craftsmen would reveal their techniques so that experimental natural philosophers could formulate general principles for their universal applicability was rather naïve. Such a move would deprive the artisans their sole possession, skill.

**Wilhelm Eduard Weber**[[32]](#endnote-32)

Most physicists and historians of science associate Wilhelm Eduard Weber (1804-91) with his unparalleled experimental precision in electrodynamics, particularly his renowned collaboration with Carl Friedrich Gauss in Göttingen. What is generally not well known, however, is that Weber’s experimental prowess and his introduction to the wave theory originated in his early fascination with improving the design of musical instruments and the lives of those built and played them. His notoriously liberal political stance as a member of the Göttingen Seven of 1837 was also evident in his acoustical research.[[33]](#endnote-33)

Like many of his general in the German territories, Weber saw science in general, and physics in particular, assisting German manufacture, which, in turn, would fuel unification. He envisaged skilled artisans working in concert with physicists to improve manufacture. Artisans, shedding their craft secrecy, were to share their valued experience with physicists, while physicists were to proffer scientific laws and equations as guidelines for musical-instrument manufacture. Similar to his work on deriving equations for organ builders discussed below, his *Elektrodynamische Maassbestimmungen* (*Electrodynamic Measurements*) sought in part “to give definite and precise instructions for future use”, with the hope that mechanicians no longer would base their work on trial and error, wasting valuable time and money repeating the same procedure over and over again.[[34]](#endnote-34) There was never a fear of physics and mathematics replacing the labor of artisans, rather a partnership was sought that would simultaneously increase Germany’s national economic ambitions as well as avoid an extremely industrialized and socially fragmented state, as was the case in Great Britain. Weber often listed the names of the mechanicians who assisted him in his various articles published in *Annalen der Physik und Chemie* (*Annals of Physics and Chemistry*). The reform-minded milieu generated by the Prussian government, searching for ways in which science and technology could bolster the Kingdom, was conducive to such research. These officials were particularly keen to assist projects relevant to music, as Prussia was at that time undergoing the most thorough and comprehensive music reform in its history.

On 19 September 1828, at the *Versammlung deutscher Naturforscher und Aerzte* (Association of German Investigators of Nature and Physicians) in Berlin, Wihelm Weber offered the fruits of his research on reed pipes in a lecture to the physics and chemistry section, subsequently published in J. C. Poggendorff’s *Annalen der Physik und Chemie*, on the compensation of organ pipes. This work was based on his doctoral dissertation and *Habilitationsschrift* (a second major work required of those wishing to teach at German universities) at the University of Halle-Wittenberg, where he studied under Johann Salomo Christoph Schweigger, editor of the *Journal für Chemie und Physik* (also known as the *Jahrbuch für Chemie und Physik*, or *Yearbook for Chemistry and Physics*).

The largest and most perfect of all musical instruments, the organ, Weber argued, suffered from one major disadvantage: its tones could not gradually swell and diminish. Thus, the range of expression organists could achieve was rather limited. Due to a change in musical tastes arising from the Romantic movement, early nineteenth-century German audiences did not simply wish to be entertained, they now wanted to be moved. Expressive instruments were therefore critical. Expression was not only important to the organ, but also to other keyboard instruments whose sounds derived from air generated by a bellows travelling though reed pipes, such as the physharmonica, aeolodicon, aeoline, and harmonium. These organ-like instruments were popular household instruments of the educated German upper-middle class during this period. Unfortunately, despite various attempts by artisans and savants to improve pipe design, the problem remained.

The organ pipe, in essence, is a longitudinally vibrating column of air, and the volume of its tone is increased and decreased by intensifying and diminishing the flow of air respectively. But, by swelling or lessening the airflow, the organist actually slightly changed the pitch of the note; even the improved reed pipes, Weber pointed out, manufactured by Christian Gottlob Kratzenstein for his speech machine, by Abbot Georg Joseph Vogler for his orchestrion, by the Dresden mechanician Friedrich Kaufmann, and by Gabriel Joseph Grenié for his *orgue expressif* suffered from this defect. After having performed a lengthy series of experiments, Weber determined the laws by which reed pipes sound, and claimed to “be in a position to produce organ pipes, which, regardless of how strong or weak the flow of air, the tone produced will always have the same pitch.”[[35]](#endnote-35)

Weber reminded his colleagues on that mid-September afternoon in the Prussian capital that the initial tone produced by a tuning fork is slightly lower in pitch than the tone generated near the end of its resonance. Transverse vibrations oscillate in a plane perpendicular to the direction of the propagation of the waves that occur within their substance. Strings and tuning forks are good examples. It is the property of all real (but not ideal) transversally vibrating bodies that their frequency of oscillation - and so the pitch of the longitudinal vibration that is thereby generated in the surrounding air (and whose direction of propagation is the plane of oscillation of the tuning fork) - is a bit lower with a strong vibration and a bit higher with a weak vibration. That is, the pitch of the sound generated in air by a tuning fork immediately after it is struck is lower than the pitch when the volume dies down. Weber conceded that this phenomenon was well known to the musicians of the period. Longitudinal vibrations oscillate in the same direction in which they propagate; air columns are good examples. And real-world longitudinally vibrating bodies possess the opposite property to transverse vibrations: unlike the sound generated by the vibrating string or tuning fork, increasing the amplitude raises the pitch of a resonating column of air. A horn blower blowing harder into his/her instrument, Weber informs us, will increase the note’s pitch. He cleverly uses the opposite properties of these two kinds of vibrations to cancel out the effects of amplitude on pitch. Weber proceeded to set up the point of the lecture:

If it were possible to connect a resonating plate of metal [reed], which vibrates transversally, and a resonating air column, which vibrates longitudinally, in such a way that they both produce simultaneously vibrations of the same velocity, it would also be possible to produce a musical instrument from these materials, which would not change its pitch, regardless of how weakly or strongly it is agitated. I have, as a matter, of face, been able to construct such an instrument.[[36]](#endnote-36)

Weber had the mechanician Johann August Daniel Oertling of Berlin weld a transversally vibrating metal reed onto a tube containing a vibrating column of air. The air column bears the longitudinal vibrations that constitute sound, while the metallic reed oscillates transversally. Both column and reed are set into vibration by blowing through a slit in the pipe, causing the reed to vibrate. In short, if the column and reed are adjusted such that the speeds of the reed and of an air particle are always synchronized, then each is compensated exactly by the other. At any moment the amplitude of an air particle in the resonating column would always be in the same ratio to the amplitude of the vibrating reed, and since the corresponding frequency of the generated wave increases with amplitude in one, and decreases in the other, they cancel each other out.

Under certain conditions the vibrations of the air column that occur in the absence of the reed will give way to the air vibrations generated by the oscillations of the metallic reed. In this case the pitch of the reed pipe decreases with an increase in airflow. Under different conditions, however, the air vibrations generated by the metal reed give way to the vibrations of the air column proper, and the pitch of the reed pipe then increases with an increase in airflow. Weber consequently reasoned that there must be a third case as one blows increasingly harder into the pipe, when the vibrations of the reed lower the pitch by precisely the same amount that the vibrations of the air column raise it.[[37]](#endnote-37) After determining by careful experimentation with the assistance of his mechanicians, the point at which the reed pipe is compensated for differently sized reeds made from diverse metals, Weber decided to determine the laws that governed the relationship of these vibrations, “so that it [the construction of the pipes] can be carried out in practice with ease.” He argued that in order to fulfill completely the criterion of compensated organ pipes, the artisan needed to construct a pipe for each tone of the scale by employing the physical laws, which Weber himself provided.[[38]](#endnote-38)

Such precision measurement required special reed pipes to meet Weber’s rigorous criteria. Since he was a physicist and not a *Handwerker*, he could not build such instruments himself. Who were the artisans to whom he turned? Thankfully, unlike seventeenth-century England, they were not “invisible technicians”- to borrow Steven Shapin’s term.[[39]](#endnote-39) Weber mentions two in particular: Christian Hoffmann (also spelled Hofman) from Leipzig and J. August D. Oertling from Berlin, both of whom specialized in (among other things) the production of scientific and mathematical instruments.[[40]](#endnote-40)

Hoffmann was the son of Johann Christian Hoffmann, *Universitätsmechanikus und Optikus* (University Mechanician and Optician) and honorary member of the Naturforschende Gesellschaft (Society of Natural Researchers) of Leipzig. Christian took over his father’s warehouse of mathematical, optical, and physical instruments on the Klöstergäßchen in 1824.[[41]](#endnote-41) In 1826 Christian became an ordinary member of the Leipzig Naturforschende Gesellschaft.[[42]](#endnote-42) As is the case with most skilled mechanicians, we know a bit about Christian Hoffmann. We know that in 1844 he applied for, and received, a privilege for a table scale, whereby no one was permitted to build a scale of similar construction for the ensuing five years.[[43]](#endnote-43) Some eleven years later, Christian turned his attention away from physical, optical, and mathematical instruments and toward publishing. In 1855 he applied to the city council for a concession to keep his journeymen. These journeymen included a carpenter, a metal purer, a blacksmith, a goldsmith, and a locksmith.[[44]](#endnote-44) A list of instruments that his mechanical institute produced in 1855 included printing presses, steel and copper pressure presses, bookbinding machines, ploughs, cylinders for paper glazing, and paper and stamp presses.

In addition to Hoffmann, Oertling was the other mechanician to whom Weber turned to build his precision physical instruments. He enjoyed a much more successful career manufacturing scientific precision instruments than Hoffmann. Originally residing in Dorotheastraße of Berlin in the 1820s, he moved to Jerusalemstraße 1, where he lived throughout the 1830s, Krausenstraße 53 in 1840, Markengrafstraße 31 un 1843, finally settling in Oranienburgerstraße 57, living there during the 1840s and ‘50s. He had three sons, all of whom were opticians and mechanics: August, C[hristian?]., and Friedrich.[[45]](#endnote-45) C[hristian?]. later became a piano manufacturer and owed an instrument shop at Potsdamerstraße 95. The father was renowned for his manufacture of precision optical instruments, many of which were used at the Potsdam Observatory during the mid-nineteenth-century, such as high-precision thermometers and a reflecting circle. His most influential work dealt with the production and testing of plano-parallel objectives for scientific instruments.[[46]](#endnote-46)

Organ builders enthusiastically responded to Weber’s work on compensated reed pipes. The piano and organ builder Carl Kützing included a brief discussion of Weber’s work on the role of the reed and air column in generating the pitch of a reed pipe in his *Beiträge zur praktischen Akustik als Nachtrag zur Fortepiano- und Orgelbaukunst* (*Contributions to Practical Acoustics as a Supplement to the Art of Piano and Organ Building*).[[47]](#endnote-47) And Germany’s leading nineteenth-century organ builder (and one of its best organists), Johann Gottlob Töpfer, drew upon Weber’s work compensated on reed pipes.

Töpfer was professor of music of the Grand Duchy of Sax-Weimar-Eisenach’s Seminar for Teachers (*Schullehrerseminar*) and organist of the city church of Weimar. Particularly fascinated by the construction of the organ in Weimar’s city church, he spent many hours in the workshops of organ builders, traveling throughout Saxony, Bavaria, Austria, and Bohemia gleaning information on organ construction and renovation.[[48]](#endnote-48)

Töpfer first alerted fellow organ builders to the acoustical work of Chladni and the Weber brothers in his *Die Orgelbau-Kunst* (*The Art of Organ Building*).[[49]](#endnote-49) Of particular importance was the brothers’ work on the acoustics of organ pipes, detailed in their *Wellenlehre* (*The Doctrine of Waves*) and summarized by them in an essay in the *Allgemeine musikalische Zeitung* (*General Music Newspaper*) in 1826.[[50]](#endnote-50) A year later in his *Erster Nachtrag zu Orgelbau-Kunst* (*First Supplement to the Art of Organ Building*), Töpfer summed by Weber’s paper “On the Theory of Reed Pipes”:

The causes whereby the pitch of a free-vibrating reed, in conjunction with pipes of varying lengths and widths changes, have been so carefully researched by Prof. Wilhelm Weber, and the laws according to which the changes themselves follow are stated so precisely and are so solidly grounded that I refer anyone who wants to learn about this point to these treaties, of these [particularly] the first-rate “Theory of Reed Pipes,” which one finds in Poggendorf’s [sic] *Annals for Physics* [sic], vol. 17.[[51]](#endnote-51)

Töpfer added, “In his ‘Theory of Reed Pipes,” Herr Prof. Weber has developed equations, by the help of which the given sizes of the free-vibrating reed pipes can be determined for certain cases.”[[52]](#endnote-52) As Oertling’s reed pipes were composed of materials different from those used in organs, Töpfer discussed the application of Weber’s work to the relevant materials. He provided his readers with numerous charts of surface areas, widths, lengths, and thicknesses of reeds for the various semitones of four octaves. Töpfer later discussed Weber’s equation and gave examples of its solutions with given dimensions of the pipe and its reed.[[53]](#endnote-53) In his abridged treatise on the organ, *Die Orgel* (*The Organ*) of 1843, Töpfer summarized Weber’s explanation of how a tone arises in a reed pipe.[[54]](#endnote-54) Weber’s research resonated with Töpfer’s, as the organ builder, disappointed that a number of key aspects of organ building were still predicated on the principle of trial and error, strove to base as much of the art on mathematical and physical principles as possible in order to increase efficiency.[[55]](#endnote-55)

The discussion and use of Weber’s equation were sufficiently relevant to organ building that it merited inclusion in Töpfer’s seminal *Lehrbuch der Orgelbaukunst* (*Textbook on the Art of Organ Building*) of 1855.[[56]](#endnote-56) Töpfer argued that if the organ builder wanted to construct a large reed pipe with great precision, so that the tube would have the same effect in all the octaves of the fundamental tone, one needed to implement Weber’s equation, which now became a part of the organ-building process.

Weber’s work, particularly his equation on determining the reed pipe’s pitch, was meant to serve as a guideline for organ builders. It certainly did not replace the tinkering necessary for the artisans to determine the required measurements. Contemporary organ builders note that each organ is unique, being built to fit its particular environment. The builder needs to take into consideration such key elements as the dimensions of the church or hall where the instrument will be houses, the range of temperatures the organ will experience throughout the year, and of course the materials used to construct it.[[57]](#endnote-57) And, Weber’s “practical law”- as the late nineteenth- and early twentieth-century organ architect Audsley labeled it - was applicable to a specific range of reed pipes only, not to all reed pipes on the organ.[[58]](#endnote-58) That said, Weber’s work did provide organ builders with a range of dimensions so that they could efficiently focus their work, saving both time and money. We never hear that the organ builders feared that physics and mechanics would one day render them redundant. And more importantly, this aspect of organ building was not hindered by secrecy. Scientific principles were seen as providing artisans with useful guidelines for the construction of compensated reed pipes.

As we have seen, the dynamic between Weber’s and the mechanicians was very different from the one between Herschel and Fraunhofer. Oertling and Hoffmann were very open in assisting Weber. And they were rewarded financially. We unfortunately do not have in-depth accounts of their interactions. Both Weber and the mechanicians possessed different skill sets, yet they could speak to each other and collaborate in mutually beneficial ways. There was no incommensurability here.

Perhaps a heading here, to mark the transition?

In conclusion, while I have previously written about both episodes, this essay looked at them through the lens provided by Fisch and Benbaji. They argue quite correctly that scientists (or experimental natural philosophers) involved in trading zones are often exposed to the explicit or implied critique of trusted practitioners of different frameworks and research traditions. The socio-cultural and economic contexts begin to explain the various rational frameworks at work in this essay. Such interactive trading can potentially challenge prior normative commitments. In addition, and perhaps more important, Fisch and Benbaji demonstrate that trading zones are often created to engage with different cultures, in this case mechanicians, to share knowledge. With the case of Weber, there was no threat. An equal exchange took place in which artisans were paid, and they learned the general equations, which they could use in their craft without fearing replacement. In return, Weber obtained his coveted reed pipes, which he employed to make crucial contributions to the study of adiabatic phenomena and to the standardization of musical phenomena, such as pitch. Of course, there are times in which members involved in trading will shield knowledge from the other party. Herschel was hoping that Fraunhofer would share with him the secrets of the Bavarian’s optical glass manufacture only to be disappointed. And rational frameworks come with their own momentum, as evinced by Herschel’s tenacity when defining the universal character of science. Trading zones are sites of rather complex and complicated social interactions, particularly when they occur between two or more individuals from different communities possessing different rational frameworks and rules of engagement. Fisch and Benbaji have provided historians of science and technology with a powerful heuristic tool with which to examine the interactions of different cultures.

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1. See Fisch and Benbaji*, The View from Within*. For the notion of trading zones, see Galison, *Image and Logic*, [↑](#endnote-ref-1)
2. Fisch, “Toward a History,” 531-532. See also Fisch and Benbaji. *The View from Within*, 286-291. [↑](#endnote-ref-2)
3. Fisch and Benbaji, *The View from Within,* p. 6. [↑](#endnote-ref-3)
4. Ibid., p. 289. [↑](#endnote-ref-4)
5. Ibid., p. 29. [↑](#endnote-ref-5)
6. This section of my essay is based on my earlier work. See Jackson, *Spectrum of Belief*, 122-136. [↑](#endnote-ref-6)
7. Royal Society of London Archives, Herschel Letters (henceforth abbreviated RS.HS.)

   Pierre Louis Guinand to John Herschel, 20 April 1822, RS.HS.13.134 . [↑](#endnote-ref-7)
8. Dollond, Herschel, and Pearson, “Report of the Committee”; Rohr, “Die Entwicklung der Kunst,” 792. [↑](#endnote-ref-8)
9. Herschel to Charles Babbage, 3 October 1824, RS.HS.2.199. [↑](#endnote-ref-9)
10. Ibid. See also *Edinburgh Journal of Science* 2 (1825): 344-348. [↑](#endnote-ref-10)
11. Herschel to Babbage, 3 October 1824, RS.HS.2.199. [↑](#endnote-ref-11)
12. Herschel to J. J. Littrow, 9 November 1824, RS.HS.11.248. [↑](#endnote-ref-12)
13. Fraunhofer gave a glass prism to Henry Fox Talbot, who passed it on to Herschel in London in 1825, Deutsches Museum Archive, Munich (henceforth DMA), Fraunhofer Nachlaß N14/20, 5389. George Dollond had previously requested that Herschel bring back glass samples from Munich (RS.HS.6.498, 31 March 1824). [↑](#endnote-ref-13)
14. Letter 332, Herschel to Faraday, Royal Institution Manuscripts F3 B397 in James, *The Correspondence of Michael Faraday*, volume 1, 438. [↑](#endnote-ref-14)
15. RS.HS.26.45, folio 1. [↑](#endnote-ref-15)
16. Seitz, *Joseph Fraunhofer*, 112. [↑](#endnote-ref-16)
17. Herschel to Reverend Brinkley (Andrews Professor of Astronomy at Trinity College, Dublin), RS.HS.4.277. No date is given for the letter, but it must have been written between 3 October and 9 November 1824. [↑](#endnote-ref-17)
18. Ibid. Underlining in the original. [↑](#endnote-ref-18)
19. Robert Fot to Herschel, 20 February 1840, RS.HS.7.348. [↑](#endnote-ref-19)
20. Prothero, *Artisans and Politics*, 198. [↑](#endnote-ref-20)
21. E. W., “London Mechanics’ Institute,” 76-77. [↑](#endnote-ref-21)
22. Herschel, *Preliminary Discourse*, 15. [↑](#endnote-ref-22)
23. Ibid., 69-70 (emphasis added). [↑](#endnote-ref-23)
24. Ibid., 63. [↑](#endnote-ref-24)
25. Ibid., 70-72. [↑](#endnote-ref-25)
26. DMA, Fraunhofer Nachlaß N14/20, 5389; Herschel, “Observations on Mr. Fraunhofer’s Memoir,” 293. [↑](#endnote-ref-26)
27. Herschel’s Minutes of the General Scientific Committee, 1827, RS.HS.26.38. [↑](#endnote-ref-27)
28. Herschel, *Preliminary Discourse*, 352. [↑](#endnote-ref-28)
29. Ibid., p. 354. [↑](#endnote-ref-29)
30. See e.g. Alder, *Engineering the Revolution*, 62 and 135. [↑](#endnote-ref-30)
31. Schaffer “Babbage’s Dancer.” [↑](#endnote-ref-31)
32. This section is based on my previous work, Jackson, *Harmonious Triads*, 114-146. [↑](#endnote-ref-32)
33. The Göttingen Seven was a group of seven Göttingen professors who protested the decision of King Ernst August of Hanover to abrogate the constitution. The members also included the literary giants Jacob and Wilhelm Grimm, and Georg Gervinus, a leading political and literary historian. [↑](#endnote-ref-33)
34. *Wilhelm Weber’s Werke*, vol. 3, 355. As translated in K. M. Olesko, “Precision, Tolerance, and Consensus,” 121. [↑](#endnote-ref-34)
35. Weber, “Compensation der Orgelpfeifen, ein Vortrag” 401. [↑](#endnote-ref-35)
36. Ibid [↑](#endnote-ref-36)
37. Ibid., 403. [↑](#endnote-ref-37)
38. Ibid., 404, 407-408. [↑](#endnote-ref-38)
39. Shapin, “The Invisible Technician,” 554-563. [↑](#endnote-ref-39)
40. Weber, “Ueber die Construction,” 206. [↑](#endnote-ref-40)
41. *Leipziger Adreßkalender* 1824, p. 210 [↑](#endnote-ref-41)
42. *Leipziger Adreßkalender* 1826, p. 80. [↑](#endnote-ref-42)
43. Stadtsarchiv Leipzig, II, Sekt. H 1518, folia 1-2. [↑](#endnote-ref-43)
44. Stadtsarchiv Leipzig, II, Sekt. H 1821, folio 1. [↑](#endnote-ref-44)
45. Entries under Oertling in the Adreßbücher, Berlin, from 1830 to 1865. See, for example, *Adress-Buch für Berlin* 1835 and *Adreß-Kalender* 1830-1837, 1840-1845, 1847-1866. [↑](#endnote-ref-45)
46. Oertling, “Ueber die Prüfung,” 60-72 [↑](#endnote-ref-46)
47. Kützing, *Beiträge zur praktischen Akustik,* 49. [↑](#endnote-ref-47)
48. Stein, “Gottlob Töpfer,” 670-672. [↑](#endnote-ref-48)
49. Töpfer, *Die Orgelbau-Kunst*. [↑](#endnote-ref-49)
50. E. H. Weber and W. E. Weber, “Allgemein fassliche Darstellung” des Vorgangens,” 185-200, 205-213, and 221-236. [↑](#endnote-ref-50)
51. Töpfer, *Erster Nachtrag*,54. [↑](#endnote-ref-51)
52. Ibid. [↑](#endnote-ref-52)
53. Ibid., 56, 60-61, 66-69, and 71-72. [↑](#endnote-ref-53)
54. Töpfer, *Die Orgel*,93-94. [↑](#endnote-ref-54)
55. Tacke, 53-54. [↑](#endnote-ref-55)
56. Töpfer, *Lehrbuch der Orgelbaukunst*,316-317. [↑](#endnote-ref-56)
57. I would like to thank Schulze Organ Builders and Restorers of Potsdam, Germany for their helpful discussions on the historical practices of organ building and restoration. [↑](#endnote-ref-57)
58. Audsley, *The Art of Organ-Building,* vol. 1, 403. [↑](#endnote-ref-58)