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Frank Krull

ORCID 0009-0000-4701-1127
Independent scholar (Neubiberg, Germany)
frank.krull@yahoo.de

Christian Gojowczyk

ORCID 0009-0000-2585-4860
Independent scholar (Leinfelden, Germany)
christian.gojowczyk@gmx.de

Albert Einstein on Scientific Writing

Abstract

This study presents an examination of Albert Einstein's statements expressing his views on scientific writing. The findings revealed that his views regarding persuasive intent, audience orientation, conciseness, and phrasing largely conformed to the contemporary writing style, but that his expectations regarding the manner of exposition clearly went beyond it.

He rejected expositions that were merely presenting completed thought constructs, which at the time were perceived as standard. Instead, he called for expositions enabling readers to follow—or, even better, to experience—the author's train of thought. Einstein considered this essential for the epistemic accessibility of scientific writings and thus for their persuasive power.

Keywords: *Albert Einstein, early 20th century physics, rhetoric of science, writing style, persuasive intent, audience orientation, epistemic accessibility*

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Albert Einstein o pisarstwie naukowym

Abstrakt

Niniejszy artykuł przedstawia analizę wypowiedzi Alberta Einsteina wyrażających jego poglądy na temat pisarstwa naukowego. Wyniki wykazały, że jego poglądy dotyczące intencji perswazyjnej, orientacji na odbiorcę, zwięzłości i frazeologii w dużej mierze odpowiadały ówczesnemu stylowi pisarskiemu, ale jego oczekiwania dotyczące sposobu prezentacji wyraźnie wykraczały poza ów styl.

Odrzucał on ujęcia, które jedynie prezentowały gotowe konstrukcje myślowe, postrzegane wówczas jako standardowe. Zamiast tego postulował ujęcia umożliwiające czytelnikom podążanie – a nawet lepsze doświadczenie – za tokiem myślenia autora. Einstein uważał to za kluczowe dla epistemicznej dostępności pism naukowych, a tym samym dla ich siły perswazyjnej.

Słowa kluczowe: *Albert Einstein, fizyka początku XX wieku, retoryka nauki, styl pisania, intencja perswazyjna, orientacja na odbiorcę, dostępność*

1. Introduction

1.1. Objective and approach

Among the studies that have analyzed Albert Einstein's (1879–1955) scientific writings are several with findings that provide insights into his views on scientific writing. These studies found that the writings examined reveal persuasive intent and various persuasive tactics. The persuasive tactics include methods to win the audience's goodwill and attention, to amplify arguments, and to support epistemic accessibility, such as audience orientation or revealing and experiencing the train of thought. Analyzing Einstein's writings is not, however, the only approach to providing insights into his views on scientific writing. His publications and correspondence include various statements expressing his views on scientific writing. Examining these statements in their original language, taking into account their biographical, historical, physical, and rhetorical contexts, offers an opportunity to obtain direct insights into the principles by which Einstein aligned and measured expositions of scientific writings.

1.2. Findings from the analyses of the writings

The individual findings from the analyses of Einstein's scientific writings on the aspects listed above are:

Locke (1992, pp. 103–112) found that the expositions of all five Einstein scientific papers that he had included in his study were designed for persuasion, with the intent to compel the reader to agree. The five papers were the 1905 papers "On a Heuristic Point of View Concerning the Production and Transformation of Light"[1], "On the Movement of Small Particles Suspended in Stationary Liquids Required by the Molecular-Kinetic Theory of Heat"[2], "On the Electrodynamics

[1] Published translation (Einstein 1989b, pp. 86–103). German original: "Über einen die Erzeugung und Verwandlung des Lichtes betreffenden heuristischen Gesichtspunkt" (Einstein 1989a, pp. 150–166).

[2] Published translation (Einstein 1989b, pp. 123–139). German original: "Über die von der molekularkinetischen Theorie der Wärme geforderte Bewegung von in ruhenden Flüssigkeiten suspendierten Teilchen" (Einstein 1989a, pp. 224–235).

of Moving Bodies"[3], the 1916 treatise "The Foundation of the General Theory of Relativity"[4], and the 1917 paper "Cosmological Considerations in the General Theory of Relativity"[5].

Lima *et al.* (2018, sect. 4) identified two methods of winning the audience's goodwill in Einstein's 1905 paper "On a Heuristic Point of View Concerning the Production and Transformation of Light". They recognized that the title itself aimed to capture the audience by anticipating possible criticism of the paper's unconventional reasoning; the arguments Einstein presented in this paper for his light quantum hypothesis were not derived using the formal apparatus of theoretical physics, but were presented as heuristic arguments. A second method to create a positive attitude from his readers toward his light quantum hypothesis was found by Lima *et al.* in the introduction. In that passage Einstein reassured the audience that the wave theory for the representation of purely optical phenomena would probably never be replaced by another theory and only then questioned its general validity.

Locke (1992, p. 105) identified an example of winning the audience's attention in Einstein's 1905 paper "On the Electrodynamics of Moving Bodies". He found that in the introduction Einstein declared that the two postulates he had raised previously—the principle of relativity and the constancy of the speed of light—were sufficient to develop a simple and consistent electrodynamics of moving bodies, but he gave the audience no notion of how he would get there. Locke concluded that this certainly created suspense and maintained the audience's attention.

Lima *et al.* (2018, sect. 4) identified a subtle example of amplifying arguments in Einstein's 1905 paper "On a Heuristic Point of View Concerning the Production and Transformation of Light". They recognized a shift in the rhetorical framing of the paper's introduction that put quantum hypothesis epistemologically over wave theory. Einstein had initially described both approaches as models of reality. However, he soon left the instrumentalist view when describing his approach and shifted to the essentialist, reality-claiming view.

Baresich (1980, pp. 125–127) found that the presentation of information in Einstein's 1905 paper "On the Electrodynamics of Moving Bodies" was properly adjusted to the knowledge and interests of the scientific audience.

Minor (1984, pp. 17–18), Locke (1992, pp. 107–112) and Heydenreich (2021, pp. 49, 53, 57, 62, and 66) concluded in their studies on Einstein's 1905 paper "On the Electrodynamics of Moving Bodies" that the thought experiments presented there by a first-person-plural we-narrator are of central importance for epistemic accessibility. Minor took the experiments as Einstein's intent to reveal to his audience the thinking process and mental images that had led him to the theory. For Locke the experiments' effect on epistemic accessibility resulted less from the fact that they were an essential part of Einstein's own thinking than that Einstein employed them for explanatory purposes. To him their telling effect resulted primarily from the fact that they were presented by a we-narrator in the voice of a patient expositor. Following Heydenreich the experiments presented by a we-narrator are to be considered a carefully and complexly configured epistemically effective narrative strategy due to their immersive, performative character. The first-person plural of the narrator is a rhetorical strategy for her to include the audience in the modeling of the theory and thus make the theory epistemically plausible.

[3] Published translation (Einstein 1989b, pp. 140–171). German original: "Zur Elektrodynamik bewegter Körper" (Einstein 1989a, pp. 276–306).

[4] Published translation (Einstein 1997, pp. 146–200). German original: "Die Grundlage der allgemeinen Relativitätstheorie" (Einstein 1996a, pp. 284–337).

[5] Published translation (Einstein 1997, pp. 421–432). German original: "Kosmologische Betrachtungen zur allgemeinen Relativitätstheorie" (Einstein,1996a, pp. 541–551).

There are further findings on the tactic of supporting epistemic accessibility for two other scientific papers by Einstein. Locke (1992, p. 110) noted that in the 1917 paper "Cosmological Considerations in the General Theory of Relativity", Einstein announced straightforwardly that he had intentionally designed the exposition to reveal his train of thought. For Einstein's 1905 paper "On a Heuristic Point of View Concerning the Generation and Transformation of Light", Johnson Sheehan, Rode (1999, pp. 348–352) found that the exposition follows a narrative pattern using an implied agent supporting the epistemic accessibility of the paper by guiding the reader through the train of thought.

2. Writing and publishing background

2.1. Native and publishing language German

Einstein wrote and published most of his scientific writings in German (Fölsing 1994, pp. 927–941). His native language was German, and German had been one of the leading international languages in the natural sciences since the second half of the 19th century (Ammon 2015, pp. 519–539, 547–563). It was therefore natural for Einstein to publish his scientific writings in international German-language scientific journals. For three decades, these were mainly the journals *Annalen der Physik* [Annals of physics], *Physikalische Zeitschrift* [Physical journal], *Zeitschrift für Physik* [Journal for physics], *Die Naturwissenschaften* [The science of nature], and *Sitzungsberichte der Königlich Preußischen Akademie der Wissenschaften* [Conference reports of the Prussian academy of sciences]. This changed when Einstein left Germany in late 1932 due to Adolf Hitler's (1889–1945) rise to power and emigrated to the US. After 1934, he no longer published any scientific writings in German journals.

2.2. Contemporary writing style

There is no study on the writing style of German scientific writings in theoretical physics at the beginning of the 20th century and therefore no findings that can be used for comparison with Einstein's views. However, statements by two contemporary colleagues provide insights into what physicists and mathematicians at the time perceived as standard. They can be found in the treatise *Development of Mathematics in the 19th Century*[6] by the mathematician Felix Klein (1849–1925) and in an essay on physicists as stylists by the physicist Hendrik Anthony Kramers (1894–1952). Both described the contemporary writing style as a particularly factual, concise, succinct, clear, and impersonal presentation of completed thought constructs and called it the classical style that had developed in the course of the 19th century (Klein 1926, pp. 3–6, 219; Kramers 1935, pp. 297–298). As exponents of this writing style, Klein named the mathematician and physicist Carl Friedrich Gauss (1777–1855), "whose works are characterized by the classical style more than any of his predecessors" (Klein 1926, p. 6)[7] and the physicist Gustav Robert Kirchhoff (1824–1887), to whom he attributed "a conciseness of exposition taken to the extreme" (Klein 1926, p. 219)[8]:

[6] Published translation (Klein 1979). German original: *Vorlesungen über die Entwicklung der Mathematik im 19. Jahrhundert* (Klein 1926).

[7] Translation by the authors. German original: "Die klassische Form seiner Werke zeichnet ihn aus wie nur irgendeinen seiner Vorgänger."

[8] Translation by the authors. German original: "Zu [der] abstrakten, sich selbst beschränkenden Auffassung vom Wesen der Wissenschaft tritt […] eine bis zum äußersten getriebene Knappheit der Darstellung."

> The style that dominated mathematical physics for several decades can largely be attributed to Kirchhoff: the principal rule is to avoid premature hypotheses or mistakes and to suppress any personal involvement, joy of discovery or wondering admiration in the face of the inexhaustibly mysterious world of phenomena (Klein 1926, p. 219).[9]

The writing styles of Gauss and Kirchhoff were already perceived as remarkable and described in detail by their contemporaries. The geologist Wolfgang Sartorius von Waltershausen (1809–1876), who was a close friend of Gauss, wrote in his biography of Gauss:

> Gauss'[s] aim was always to give his investigations the form of perfect works of art. He would not rest sooner and never gave a piece of work to the public until he had given it the perfection of form he desired for it. A good building should not show its scaffolding when completed, he used to say. In his demonstrations he used almost entirely the synthetic method, which he had come to prize through his studies of Archimedes and Newton. It is distinguished from the analytic method by its brevity and comprehensiveness. But the road leading to the discovery remains veiled, and indeed it often seems that Gauss frequently and intentionally turned aside from the road that led to mere instruction (von Waltershausen 1966, p. 67).[10]

The chemist Robert von Helmholtz (1862–1889), who had known Kirchhoff since childhood through the close relationship between his father, the physician, physiologist, and physicist Hermann von Helmholtz (1821–1894), and Kirchhoff, wrote in his memoir of Kirchhoff:

> Kirchhoff's style, like his delivery, was a model of the most clear and concise diction, absolutely classical in the subject concerned. The words stand as if hewn in stone, each one at its place, the logical comprehension of each duly considered: we find here condensed into a few lines what would have taken others pages to describe; only when the existing words seemed not precise enough, he uses circumlocutions and definitions, and that mostly in mathematical language. He held the highest rank among those who strove to remove from exact sciences all want of clearness, all subjective judgments, all phrases (von Helmholtz 1890, pp. 533–534).[11]

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[9] Translation by the authors. German original: "Von Kirchhoff schreibt sich wesentlich der Stil her, der mehrere Jahrzehnte die mathematische Physik beherrschte: als vornehmstes Gesetz das Vermeiden voreiliger Hypothesen oder gar Fehler anzusehen und jede persönliche Anteilnahme, Entdeckerfreude oder staunende Bewunderung vor der unerschöpflich geheimnisvollen Welt der Erscheinungen zu unterdrücken."

[10] German original in von Waltershausen (1856, p. 82): "Es war zu aller Zeit Gauss' Streben seinen Untersuchungen die Form vollendeter Kunstwerke zu geben: eher ruhete er nicht und er hat daher nie eine Arbeit veröffentlicht bevor sie diese von ihm gewünschte durchaus vollendete Form erhalten hatte. Man dürfe einem guten Bauwerke, pflegte er zu sagen, nach seiner Vollendung nicht mehr das Gerüste ansehen. In seiner Darstellung bediente er sich fast immer der synthetischen Methode, die er beim Studium des Archimed und Newton lieb gewonnen hatte. Sie ist zwar an Kürze und Bündigkeit vor der analytischen Methode ausgezeichnet; allein der Gang der Entdeckung bleibt verschleiert und es scheint öfter, dass er den Weg zum blossen Zwecke der Belehrung absichtlich in seinen Schriften nicht habe betreten wollen."

[11] German original in von Helmholtz (1888, p. 239): "Kirchhoff's Stil ist eben, wie es sein Vortrag war, das Muster von knappster, klarster Diction, ein für sein Gebiet absolut classischer. Wie in Stein gehauen stehen die Worte da, jedes an seiner Stelle, keines, dessen genauester logischer Umfang nicht überlegt wäre; in wenigen Zeilen ist zusammengefaßt, worüber Andere Seiten schreiben würden; nur wenn vorhandene Worte ihm nicht präcise genug scheinen, umschreibt und definirt er, und zwar dann mit Vorliebe in mathematischer Ausdrucksweise. War er doch unter jenen der Erste, die danach gestrebt haben, aus der exacten Wissenschaft jede Unklarheit, jede subjective Beurtheilung oder gar jede Phrase zu entfernen."

3. Persuasive intent

Einstein's statements on the intended effect of scientific writings indicate that he took a persuasive intent for granted. He explicitly addressed the persuasive intents of several of his own papers. In his 1905 paper "On a Heuristic Point of View Concerning the Production and Transformation of Light" he expressed "the hope that the point of view to be elaborated may prove of use to some researchers in their investigations" (Einstein 1989b, p. 87).[12] And in his 1917 paper "Cosmological Considerations in the General Theory of Relativity" he noted the "hope that [the reader] will take much interest in the result at the end of the journey" (Einstein 1997, pp. 423–424).[13]

The fact that Einstein expressed the persuasive intent implicitly rather than overtly in these two papers is probably due to rhetorical restraint. He was not that restrained in all cases. In his 1916 treatise "The Foundation of the General Theory of Relativity", for example, he addressed his persuasive intent quite explicitly: "My main object is to develop this theory in such a way that the reader will feel that the path we have entered upon is psychologically the natural one" (Einstein 1997, p. 154).[14]

In addition to Einstein's statements on his own intents, he addressed the intended effect of other authors' writings. Those concerning Hermann Weyl's (1885–1955) 1918 book *Space–Time–Matter*[15] are particularly significant. Einstein and the mathematician and physicist Weyl were colleagues at the Swiss Federal Institute of Technology in Zurich between 1912 and 1914 and remained in close contact after that time. As a result of their closeness, Einstein commented on the persuasive quality of the book not only in a review in the journal *Die Naturwissenschaften* but also in several letters and postcards to Weyl. Einstein repeatedly admired Weyl's ability to create an epistemic accessibility for his trains of thought (Einstein 1998b, pp. 669–670, 724, 824; Einstein 2002a, p. 79). The book appeared so convincing to Einstein that he found Weyl's expositions "self-evident" (Einstein 2002b, p. 62)[16] and coming out "naturally" (Einstein 1998c, p. 491).[17]

Despite his admiration for the persuasive power of Weyl's expositions, Einstein made it clear in another letter he sent to Weyl in 1918 that he appreciated persuasive expositions only if the train of thought presented could claim to be true. In this letter, Einstein raised substantive objections to another publication by Weyl and appealed to him to give priority to truth over rhetoric despite his persuasive abilities, which impressed Einstein once again:

> You know, of course, how I conceive the relation to reality; nothing has changed in this regard. I know how much easier it is to convince people than to find truths, especially

[12] German original in Einstein (1989a, p. 151): "Im folgenden will ich den Gedankengang mitteilen und die Tatsachen anführen, welche mich auf diesen Weg geführt haben, in der Hoffnung, daß der darzulegende Gesichtspunkt sich einigen Forschern bei ihren Untersuchungen als brauchbar erweisen möge."

[13] German original in Einstein (1996a, p. 543): "Im folgenden führe ich den Leser auf dem von mir selbst zurückgelegten, etwas indirekten und holperigen Wege, weil ich nur so hoffen kann, daß er dem Endergebnis Interesse entgegenbringe."

[14] German original in Einstein (1996a, p. 292): "Es ist mein Hauptziel, diese Theorie so zu entwickeln, daß der Leser die psychologische Natürlichkeit des eingeschlagenen Weges empfindet."

[15] Published translation (Weyl 1922). German original: *Raum · Zeit · Materie* (Weyl 1918).

[16] German original in Einstein (2002a, p. 79), emphasis in original: "Hier sieht man ganz besonders mit Staunen, wie in *Weyls* Händen das Komplizierteste einfach und selbstverständlich wird."

[17] German original in Einstein (1998b, pp. 669–670): "Jedes Wörtchen hat seine Beziehung zum Ganzen und die Anlage des Werkes ist grandios. Die prachtvolle Methode der infinitesimalen Parallel-Verschiebung von Vektoren zur Ableitung des Riemann-tensors! Wie natürlich sich das alles macht."

> for someone who is such an incredible master of exposition as you are (Einstein 1998c, p. 654).[18]

Locke (1992, pp. 103–112) confirms that Einstein's persuasive intent is clearly evident in several of his scientific papers.[19]

4. Audience orientation

Einstein's statements on audience orientation of scientific writings show his clear awareness of audiences of both his own works and of other authors. One example that illustrates how audience-oriented he was in his writing can be found in his letter to the physicist Johannes Stark (1874–1957) from November 1907. Stark was the editor of *Jahrbuch der Radioaktivität und Elektronik* [Yearbook of radioactivity and electronics], which addressed a broad readership in the natural sciences, engineering, and medicine. He had asked Einstein to write an article on relativity for the 1907 yearbook. In his November letter, Einstein not only reported to Stark that he was making good progress with writing "On the Relativity Principle and the Conclusions Drawn from It"[20], but also explained to him how he had designed the text to enable the audience of the yearbook to read it as an easy-to-understand introduction. He wrote that he "designed the article in such a way that, with its help, anyone can relatively easily familiarize oneself with the relativity theory and its applications to date." He then detailed the qualities he had in mind when writing the article:

> I have taken great care in explaining the assumptions used—as far as possible, I have introduced each assumption one by one and have traced their consequences in the same order. Also, I attached greater importance to the intuitiveness and simplicity of the mathematical developments than to the unity of presentation (Einstein 1995b, pp. 44–45).[21]

In the introduction to his 1916 treatise "The Foundation of the General Theory of Relativity", Einstein explained the audience orientation of his paper directly to the readers. He explicitly pointed out that, since the work was to be published in a journal addressed primarily to physicists, he therefore:

> developed all the necessary mathematical tools—which cannot be assumed to be known to every physicist—and I tried to do it in as simple and transparent a manner as possible, so that a special study of the mathematical literature is not required for the understanding of the present paper (Einstein 1997, p. 146).[22]

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[18] German original in Einstein (1998b, p. 893): "Wie ich über das Verhältnis zur Realität denke, wissen sie ja; es hat sich nichts dran geändert. Ich weiss, wie viel leichter es ist, Menschen zu überzeugen, als Wahrheit zu finden, besonders für einen, der ein so unerhörter Meister der Darstellung ist wie Sie."

[19] See section 1.2.

[20] Published translation (Einstein 1989b, pp. 252–311). German original: "Über das Relativitätsprinzip und die aus demselben gezogenen Folgerungen" (Einstein 1989a, pp. 433–484).

[21] German original in Einstein (1993, pp. 77–78): "Ich habe die Arbeit so angelegt, dass sich an Hand derselben jeder relativ leicht in die Relativitätstheorie und deren bisherige Anwendungen einführen kann. An die Klarlegung der benutzen Annahmen habe ich viel Sorgfalt verwendet, indem ich – soweit es anging – jene Annahmen einzeln einführte und der Reihe nach ihre Konsequenzen verfolgte. Auch habe ich mehr Gewicht gelegt auf Anschaulichkeit und Einfachheit der mathematischen Entwicklungen, als auf Einheitlichkeit der Darstellung."

[22] German original in Einstein (1996a, p. 284): "Ich habe […] alle für uns nötigen, bei dem Physiker nicht als bekannt vorauszusetzenden mathematischen Hilfsmittel in möglichst einfacher und durchsichtiger Weise entwickelt, so daß ein Studium mathematischer Literatur für das Verständnis der vorliegenden Abhandlung nicht erforderlich ist."

Einstein went even further in the foreword to his 1922 collection of four lectures on the theory of relativity held at Princeton University in May 1921. In this case, he did not explain how he aligned the text with a target audience. Rather, he defined his target audience by explaining his aim for the publication. He declared that his intent in presenting a summary of his main thoughts and mathematical methods was to address "all those who master the elements of higher mathematics, but do not want to spend all too much time and effort on the subject." For them, Einstein wrote, "I have made an effort to leave out everything that is less essential, but to treat the fundamentals in such a way that the whole may serve as an introduction" (Gutfreund, Renn 2017, p. 5).[23]

An example showing that Einstein also paid attention to the audience orientation of other authors' writings can be found in his 1905 review of *An Outline of the Theory of Heat*[24], published by the engineer and mathematician Jakob Johann von Weyrauch (1845–1917). There he confirmed that the book, whose title suggested it was suitable for self-study, had precisely that quality. Einstein explained his judgment of the work's audience orientation, writing:

> Much care has been devoted to the didactic aspects in order to accomplish the above purpose. In order to present the theory in a compact and clear form, as well as to impress the abstract results obtained upon the reader's mind as vividly as possible, numerous examples and problems are inserted between the theoretical presentations (Einstein 1989b, p. 178).[25]

The findings in Baresich (1980, pp. 125–127) confirm that Einstein's audience orientation is evident in at least the one scientific paper he examined.[26]

5. Conciseness and phrasing

Einstein's statements regarding the conciseness and phrasing of scientific writings show clearly that he took the contemporary writing style[27] for granted in these two aspects. He considered the quality attributes of factuality, succinctness, conciseness, and clarity to be compulsory and appropriate. He even recommended them to other scientists. In February 1908, for example, the physicist Jakob Laub (1884–1962), who was working with Einstein on joint papers on the special theory of relativity, thanked him in a letter for his "remarks regarding my manner of expressing myself," in particular for Einstein's advice on "precise and clear formulation" (Einstein 1995b, p. 55).[28] In January 1913, in a letter to the physical chemist Georg Bredig (1868–1944), Einstein directed the following recommendation to Bredig's student, Michael Polanyi (1891–1976): "If I might wish for one thing regarding the papers, it would be greater conciseness. This would

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[23] German original in Einstein (2002a, p. 499): "Dabei habe ich mich bemüht, alles weniger Wesentliche wegzulassen, das Grundsätzliche aber doch so zu behandeln, daß das Ganze als Einführung für alle diejenigen dienen kann, welche die Elemente der höheren Mathematik beherrschen, aber nicht allzuviel Zeit und Mühe auf den Gegenstand verwenden wollen."

[24] Translation by the authors. German original: *Grundriss der Wärme-Theorie* (Weyrauch 1905).

[25] German original in Einstein (1989a, p. 329): "Auf die Vollendung desselben [wurde] in didaktischer Beziehung große Sorgfalt verwendet […]. Um einerseits die Theorie in geschlossener, übersichtlicher Form darstellen zu können und andererseits dem Leser die entwickelten abstrakten Resultate möglichst lebendig zum Bewußtsein zu bringen, sind zwischen die theoretischen Darlegungen zahlreiche Beispiele und Aufgaben eingeschaltet."

[26] See section 1.2.

[27] See section 2.2.

[28] German original in Einstein (1993, p. 94): "Ihre Bemerkungen, welche sich auf meine Ausdrucksweise beziehen, sind vollkommen berechtigt. […] Und der exakte, klare Ausdruck spielt doch gerade in diesen Sachen eine grosse Rolle […] Ich versichere Sie, dass ich Ihre Ratschläge befolgen werde."

make them even more persuasive" (Einstein 1995b, p. 329).[29] To Hans Wittig, an engineer who had been working on a publication on the space and time problem of psychology and who had asked Einstein in 1920 if he could dedicate the publication to him, Einstein wrote back that he would be happy to check the work and would gladly accept the dedication, provided he found the exposition "clear," "to the point," and "sober" as, in Einstein's view, "truth tends to appear modestly and in simple dress" (Einstein 2006b, pp. 151–152).[30]

For Einstein, conciseness in scientific writings meant "to present the matter as succinctly as possible, free of all unnecessary trimmings" (Einstein 1998c, p. 264).[31] This is what he wrote in a November 1916 letter to his friend, the physicist Hendrik Antoon Lorentz (1853–1928). There Einstein declared that he had deliberately kept his latest publication concise; "Hamilton's Principle and the General Theory of Relativity"[32] is only five and a half pages long.

Two other statements in which Einstein praised publications for the selection of the considered content make it clear that conciseness meant for him focusing on the essentials. One of these is in a letter of recommendation for a job appointment, which he sent to the physicist Willem Henri Julius (1860–1925) in December 1911. There Einstein, in his assessment of the physicist Willem Hendrik Keesom (1876–1956), pointed out that the encyclopedic treatise "The equation of state"[33], which Keesom had recently completed with the physicist Heike Kamerlingh Onnes (1853–1926), "reveals, throughout, a keen eye for what is important and interesting" (Einstein 1995b, p. 237).[34] With similar compliments, only in different words, Einstein appreciated the publication *Space and Time in Contemporary Physics*[35] by the physicist and philosopher Moritz Schlick (1882–1936). In February 1917, he replied to Schlick's manuscript with an enthusiastic letter in which he attested that Schlick had "said all that is essential, and omitted all that is unessential" (Einstein 1998c, p. 284).[36]

Clear, precise phrasing had become a standard for Einstein, presumably due in part to his time from 1902 to 1909 serving as a technical expert at the Bern patent office while simultaneously working on his first scientific writings. In a July 1917 letter to his friend, the forensic pathologist Heinrich Zangger (1874–1957), he apologized for his critical comments on the correction proofs of Zangger's latest publication by pointing out that "it may well be possible that my perpetual ride on my own hobbyhorse and the conventions at the Patent Office have driven my standards

[29] German original in Einstein (1993, p. 514): "Wenn ich eines an den Arbeiten wünschen möchte, so wäre es grössere Kürze. Dadurch werden sie an Ueberzeugungskraft nur zunehmen."

[30] German original in Einstein (2006a, p. 245): "Im Falle ich [Ihre Arbeit] sachlich und klar finde, will ich Ihre Widmung gern annehmen […]. Verdächtig erscheinen mir in Ihrem Briefe die hochtönenden Worte und revolutionären Gesten; Wahrheit pflegt bescheiden und in schlichtem Gewande einherzugehen. […] Einstweilen nur einen Rat: Nüchterne Ausdrucksweise."

[31] German original in Einstein (1998a, p. 363): "Die Sache so kurz als nur möglich darzustellen, frei von allem unnötigem Beiwerk."

[32] Published translation (Einstein 1997, pp. 240–246). German original: "Hamiltonsches Prinzip und allgemeine Relativitätstheorie" (Einstein 1996a, pp. 410–415).

[33] Translation by the authors. German original: "Die Zustandsgleichung" (Kamerlingh Onnes, Keesom 1911).

[34] German original in Einstein (1993, p. 374): "Es zeigt sich überall ein scharfer Blick für das Wichtige und Interessante."

[35] Published translation (Schlick 1920). German original: "Raum und Zeit in der gegenwärtigen Physik" (Schlick 1917a and 1917b).

[36] German original in Einstein (1998a, p. 389): "Sie haben […] alles Wesentliche gesagt und alles Unwesentliche weggelassen."

to exaggerated heights in this regard" (Einstein 1998c, p. 361).[37] In fact, the duties of the technical experts at the patent office were characterized in a 1907 patent office memorandum as ensuring "that the invention [filed] is described in a technically correct, well-arranged and clear manner" (Hentschel, Graßhoff 2005, p. 44).[38] Einstein described his own work at the patent office in an autobiographical sketch from 1955 as "work on the definitive formulation of technical patents" (Einstein 1993, p. 81, fn. 5).[39] In his seven years at the office, he had processed about two thousand patent applications (Hentschel, Graßhoff 2005, pp. 48–52). In the only objection note to one of these applications that has survived, Einstein precisely criticized that "the patent claim is […] imprecisely, and unclearly prepared" (Einstein 1995b, p. 46).[40]

Considering his high expectations of both himself and others, Einstein was clearly uncomfortable when an imprecise, misleading phrasing occurred in one of his own writings. This can be seen in his reaction to a critique concerning his 1917 paper "Cosmological Considerations in the General Theory of Relativity" by the astronomer Willem de Sitter (1872–1934) and the physicist Gustav Mie (1868–1957). In the correspondence with his colleagues, Einstein expressed his impression that the critique was due to imprecise phrasing that had led to misunderstandings. Einstein's February 1918 letter to Mie shows that he was disappointed with himself for having been misunderstood because of imprecise phrasing: "From the last exposition in your letter I unfortunately see, as in many other instances already, that my Academy paper 'Cosmol. Considerations' is being totally misunderstood. Apparently, I did not express myself precisely enough" (Einstein 1998c, p. 486).[41]

Einstein's statements suggest that his scientific papers would show conciseness and a clear, precise phrasing. Unfortunately, no study has yet examined whether this is true. Nor has any study examined how Einstein's scientific writing style was perceived by his contemporary colleagues. The perceptions of contemporary mathematicians and physicists cited in published sources and literature on Einstein are too few to draw any conclusions.[42]

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[37] German original in Einstein (1998a, p. 495): "Es ist wohl möglich, dass das ewige Reiten auf dem eigenen Steckenpferd und die Praxis im Patentamt meine Ansprüche in dieser Beziehung allzusehr in die Höhe getrieben haben."

[38] Translation by the authors. German original: "Der technische Experte des Amtes hat darauf zu achten und dafür zu sorgen, […] dass die Erfindung technisch richtig, übersichtlich geordnet und klar erläutert werde."

[39] German original in Einstein (1955a, p. 147): "Arbeit an der endgültigen Formulierung technischer Patente."

[40] German original in Einstein (1993, p. 80): "Der Patentanspruch ist […] ungenau und unklar redigiert."

[41] German original in Einstein (1998b, p. 661): "Aus der letzten Darlegung Ihres Briefes sehe ich leider wie schon öfter, dass meine Akademie-Abhandlung 'kosmol. Betrachtungen' total missverstanden wird. Ich habe mich dort augenscheinlich nicht exakt genug ausgedrückt."

[42] The authors of this study have found the following published perceptions:

In Einstein (1993, p. 156): The physicist Wilhelm Wien (1864–1928), coeditor of the journal *Annalen der Physik*, requested that Einstein be a little more detailed in his recently submitted comment on a paper of the mathematician Dmitry Mirimanoff (1861–1945). Wien explained in his letter to Einstein on January 19, 1909, that the note had not been clear to him and that he assumed that this would probably be the case for many other readers.

In Seelig (1960, pp. 166–168): A memorandum from Einstein's doctoral dissertation advisor, the physicist Alfred Kleiner (1849–1916), which he sent to the Philosophical Faculty II of the University of Zurich on February 23, 1909, recommending Einstein for the position of extraordinary professor of theoretical physics (Einstein 1993, p. 160, fn. 2). In this endorsement, Kleiner emphasized the clarity and precision of Einstein's writing style as remarkable.

In Einstein (2015, p. 679): A request addressed to Einstein from the mathematician David Hilbert (1862–1943) to contribute to the journal *Mathematische Annalen* [Mathematical annals] a more detailed version of his papers on the quantum theory of the monatomic ideal gas published in 1924 and 1925 in the *Sitzungsberichte der Königlich Preußischen Akademie der Wissenschaften*. In his letter sent to Einstein on February 28, 1925, Hilbert explained the request by pointing out that the academy version was quite difficult to read.

6. Manner of exposition

Einstein's expectations for the epistemic accessibility of scientific writing clearly went beyond the prospect that the mathematics and exemplifications need to be adjusted to the level of the audience and that the exposition needs to be concise and the phrasing clear and precise. He expected and aimed for an exposition providing an epistemic accessibility that would allow readers to really grasp the results. This expectation included that the exposition would reveal the author's train of thought. For scientific writings to be epistemically accessible required, in his view, that expositions do more than merely present completed thought constructs. His statements make this very clear.

6.1. Unrestrained openness

Prominent examples reflecting this expectation are his reviews of Lorentz's collections of lecture notes, *The Principle of Relativity*[43] and *Statistical Theories in Thermodynamics*[44], which Einstein published in the journal *Die Naturwissenschaften* in 1914 and 1916. Here, Einstein took the exemplary exposition of the two publications as an occasion to vividly demonstrate to the scientific community his critique on expositions that were merely presenting completed thought constructs.

Both of Einstein's reviews open with recalling the frustrations often experienced by scientists when reading such expositions: the disappointment of finding only completed thought constructs and not being given the opportunity to reconstruct their development, and the disillusionment that the results can be verified only formally and that the underlying guiding ideas remain hidden:

> Many writers are able to present a given theory clearly and concisely. But the reader is almost always confronted with a finished result; he doesn't experience the pleasure of searching and finding, the vibrant development of thoughts. He seldom gains a clear understanding of what led to following the chosen path and no other (Einstein 1996a, p. 135).[45]

> Whoever has studied mathematical theories has had the following, embarrassing experience: he verifies every step in a deduction with diligence and eagerness, and at the end of his efforts he understands *nothing*. He did not get the guiding idea of the whole concept because the author himself suppressed it, either from an incapacity to phrase it concisely, or worse, from an almost comical coquettishness—as the insightful would say—which was especially popular in the past (Einstein 1997, p. 218, emphasis in original).[46]

Thus, the contemporary readers of Einstein's reviews got a concrete idea of his critique from his first sentences. In vigorously drawing the shortcomings of others' writings, Einstein turned his

[43] Translation by the authors. Dutch original: *Het Relativiteitsbeginsel* (Lorentz 1913). Published German translation: *Das Relativitätsprinzip* (Lorentz 1914).

[44] Translation by the authors. French original: *Les théories statistique en thermodynamique* (Lorentz 1916).

[45] Translation by the authors. German original: "Es gibt nicht wenige Autoren, die eine vorliegende Theorie klar und übersichtlich darzustellen vermögen. Aber fast immer sieht sich der Leser einem Fertigen gegenüber; er erlebt nicht die Freude des Suchens und Findens, des lebendigen Werdens der Gedanken, er gelangt selten zu einer klaren Kenntnis der Umstände, die dazu Anlaß geben, gerade den gewählten und keinen anderen Weg zu wandeln."

[46] German original in Einstein (1996a, p. 375): "Jeder, der mathematische Theorien studiert hat, kennt folgendes peinliche Erlebnis: Er verifiziert mit Fleiß und Eifer jeden Schritt der Deduktion und versteht am Ende seiner Bemühungen — nichts; es fehlt ihm der leitende Konzeptionsgedanke, den der Autor häufig aus Unvermögen, ihn sauber auszudrücken, oder gar aus einer besonders früher üblichen, den Sehenden fast komisch berührenden Koketterie unterdrückt."

compliments for Lorentz's publications, where "the reader *experiences* the development of the thought" (Einstein 1996a, p. 135, emphasis in original)[47] and "the guiding ideas are sharply focused upon," (Einstein 1997, p. 218)[48] into more than reading recommendations. Readers could thus take the reviews as calls to do as Lorentz did. Einstein presumably wanted his reviews to be understood in this way. His conclusion to the introduction of his review of Lorentz's *Statistical Theories in Thermodynamics* suggests this. There he called directly on readers to risk expositions that reveal their trains of thought: "This evil can only be overcome by unrestrained openness of the author, who should not shy away from familiarizing the reader even with his incomplete guiding ideas if they have furthered his own work" (Einstein 1997, p. 218).[49]

6.2. Two negative examples

In his review of *Statistical Theories in Thermodynamics*, Einstein also illustrated his critique by presenting a concrete negative example: the treatise *Elementary Principles in Statistical Mechanics*[50] by the engineer, mathematician and physicist Josiah Willard Gibbs (1839–1903). Published in English in 1902 and in German translation in 1905, the book was widely known in the scientific community. Einstein made intensive use of it and gave its content his highest appreciation. Einstein called the book "pioneering." He offered the critique, however, that Gibbs "has sinned quite a lot against [the] commandment" to reveal the guiding ideas in his work, with the result that "many have read it, many have verified it—and did *not* understand it" (Einstein 1997, p. 218, emphasis in original).[51] In a letter to the engineer Michele Besso (1873–1955), his university friend and former colleague at the Bern patent office, he made a similar comment. He wrote in June 1918, "Besides, Gibbs's book is a masterpiece, although hard to read and with the main points between the lines" (Einstein 1998c, p. 598).[52]

Another concrete negative example, which Einstein criticized on another occasion for not revealing the train of thought as he expected it should have been, was the paper "The Foundations of Physics"[53] published in 1916 by the mathematician David Hilbert (1862–1943). In a postcard written to his physics colleague and friend Paul Ehrenfest (1880–1933) in May 1916, Einstein expressed his deep disappointment about the work that had recently appeared in print:

[47] Translation by the authors. German original: "Bei der Lektüre des vorliegenden Werkchens dagegen *erlebt* der Leser die Entwicklung der Gedanken."

[48] German original in Einstein (1996a, p. 376), emphasis in original: "*Lorentz* [hat] […] die Grundlagen der Theorie […] so dar[ge]stellt, daß die leitenden Gedanken scharf hervortreten."

[49] German original in Einstein (1996a, p. 375): "Gegen dies Übel hilft nur schrankenlose Offenheit des Autors, der sich nicht scheuen soll, auch unvollkommenere Leitideen dem Leser anzuvertrauen, wenn sie sein Werk gefördert haben."

[50] English original (Gibbs 1902). Published German translation: *Elementare Grundlagen der statistischen Mechanik* (Gibbs 1905).

[51] German original in Einstein (1996a, p. 376), emphasis in original: "Jeder Kundige wird mir darin beistimmen, daß sich *Gibbs* in seinem bahnbrechenden Buche über den Gegenstand schwer gegen dies Gebot versündigte; viele haben es gelesen, verifiziert und *nicht* verstanden."

[52] German original in Einstein (1998b, p. 815): "Das Gibbs'sche Buch ist übrigens ein Meisterwerk, wenn auch hart zum Lesen und die Hauptsache zwischen den Zeilen."

[53] Published translation (Hilbert 2007). German original: "Die Grundlagen der Physik" (Hilbert 1916).

> Hilbert's description doesn't appeal to me. It is […] unnecessarily complicated, and not straightforward (= Gauss-like) in set-up (feigning the super-human through concealment of the methods) (Einstein 1998c, p. 213).[54]

A few days later, Einstein offered his critique directly to Hilbert. When Einstein was preparing a presentation on the paper for a physics colloquium, he got stuck on some results, unable to grasp how Hilbert had derived them. He therefore sent a postcard to Hilbert, with the request to assist him with instructions (Einstein 1998a, pp. 289–290). Hilbert answered him a few days later with detailed explanations (Einstein 1998a, pp. 290–291), for which Einstein thanked him immediately. However, he could not resist commenting that he would have had less difficulty understanding if Hilbert had revealed the train of thought guiding him in his work:

> Why do you make it so hard for poor mortals by withholding the technique behind your ideas? It surely does not suffice for the thoughtful reader if, although able to verify the correctness of the equations, he cannot have a clear view of the overall plan of the analysis (Einstein 1998c, p. 216).[55]

Since Einstein had been in a scientific competition with Hilbert a few months earlier over claims concerning the general theory of relativity, one might assume that the harshness with which he criticized the paper was due to a lingering resentment toward Hilbert. However, a letter that the mathematician Felix Klein (1849–1925), who was very close with Hilbert, sent to the physicist Wolfgang Pauli (1900–1958) in May 1921 indicates that this was not the case. In the letter, Klein also criticized Hilbert in harsh words for not revealing his train of thought in his paper (Hermann, von Meyenn, Weisskopf 1979, p. 31).

6.3. Communicate the train of thought

Einstein's expectation that readers of scientific writings must be able to follow the author's train of thought can also be found in statements on his own writings. A notable example of this is provided by two postcards that Einstein sent on March 11, 1912, to the physicist Wilhelm Wien (1864–1928), coeditor of the journal *Annalen der Physik*. It concerned the manuscript of his paper "The Speed of Light and the Statics of the Gravitational Field"[56], which he had submitted two weeks earlier. Einstein had noticed in the meantime that the field equations he derived heuristically were not tenable. He therefore wrote to Wien on the morning of March 11 that he would like to withdraw the manuscript and correct it. On the same day, however, he changed his mind and sent a second postcard following the first, in which he asked Wien to publish the paper as it stood. He explained his change of mind by pointing out that he wanted to give readers the opportunity to follow his train of thought: "I think I should let the thing stand as it is, so that those interested in the problem can see how I arrived at the formulas" (Einstein 1995b, p. 273).[57] He therefore added

[54] German original in Einstein (1998a, p. 288): "Hilberts Darstellung gefällt mir nicht. Sie ist […] unnötig kompliziert, nicht ehrlich (= Gaussisch) im Aufbau (Vorspiegelung des Übermenschen durch Verschleierung der Methoden)."

[55] German original in Einstein (1998a, p. 293): "Warum machen Sie es dem armen Sterblichen so schwer, indem Sie ihm die Technik Ihres Denkens vorenthalten? Es genügt doch dem denkenden Leser nicht, wenn er zwar die Richtigkeit der Gleichungen verifizieren aber den Plan der ganzen Untersuchung nicht überschauen kann."

[56] Published translation (Einstein 1996b, pp. 95–106). German original: "Lichtgeschwindigkeit und Statik des Gravitationsfeldes" (Einstein 1995a, pp. 130–144).

[57] German original in Einstein (1993, p. 429): "Ich glaube die Sache doch so lassen zu sollen, damit diejenigen, welche sich für das Problem interessieren, sehen, wie ich zu den Formeln gekommen bin."

only a footnote to the paper pointing out the deficiency and announcing that he would write a correction in a subsequent paper (Einstein 1995a, p. 135), which he did (Einstein 1995a, pp. 147–162).

Einstein's standards as an author are even more apparent in an advertisement in the journal *Die Naturwissenschaften*, which he himself wrote, promoting the separately purchasable offprint of his 1916 treatise "The Foundation of the General Theory of Relativity". There he explicitly pointed out:

> The guiding consideration for the exposition was to ensure it would provide the clearest possible understanding of the methods used to establish the theory (Einstein 1996a, p. 379).[58]

Even Einstein's scientific writings include direct statements revealing his authorial standards. This is particularly evident in the remarks:

> I wish to communicate my train of thought and present the facts that led me to this course (Einstein 1989b, p. 87)[59]

in his 1905 paper "On a Heuristic Point of View Concerning the Production and Transformation of Light" and

> In the present paragraph I shall conduct the reader over the road that I have myself travelled, rather a rough and winding road" (Einstein 1997, p. 423)[60]

in his 1917 paper "Cosmological Considerations in the General Theory of Relativity".

6.4. Experience the inner struggle

For Einstein, revealing the train of thought alone did not lead to the best possible epistemic accessibility of scientific writings. He expected that the reader should not only be able to follow the train of thought, but to experience it as well. This expectation can clearly be read in Einstein's 1914 review of Lorentz's lecture notes, *The Principle of Relativity*. There he explicitly pointed out that the reader of a scientific paper that offers only an exposition presenting completed thought constructs misses the emotional satisfaction offered by an exposition revealing the train of thought: "He doesn't experience the pleasure of searching and finding, the vibrant development of thoughts" (Einstein 1996a, p. 135).[61]

There is also a secondhand account of a statement by Einstein where he directly called for a scientific exposition enabling the reader to experience the author's train of thought. It is part of the notes the physicist and historian Robert Sherwood Shankland (1908–1982) took of his conversations with Einstein. He reported that Einstein had strongly recommended him to write his intended historical exposition of the Michelson-Morley experiment the same way Ernst Mach

[58] Translation by the authors. German original: "Der leitende Gesichtspunkt für die Darstellung war, daß letztere einen möglichst deutlichen Einblick in die Methoden gewähren sollte, nach denen die Theorie tatsächlich aufgefunden wurde."

[59] German original in Einstein (1989a, p. 151): "Im folgenden will ich den Gedankengang mitteilen und die Tatsachen anführen, welche mich auf diesen Weg geführt haben."

[60] German original in Einstein (1996a, p. 543): "Im folgenden führe ich den Leser auf dem von mir selbst zurückgelegten, etwas indirekten und holperigen Wege."

[61] Translation by the authors. German original: "Er erlebt nicht die Freude des Suchens und Findens, des lebendigen Werdens der Gedanken."

(1838–1916) had reconstructed trains of thought from the history of physics in his book *The Science of Mechanics*[62] (Shankland 1963, p. 50).

Einstein's emotional response to writings that allowed him to truly experience the train of thought can be found in his reflections on two books. In his 1949 memorial to the philosopher and jurist Morris Raphael Cohen (1880–1947), Einstein described how much Cohen's and Ernest Nagel's (1901–1985) book *An Introduction to Logic and Scientific Method*[63], published in 1934, had fascinated him because he could experience the authors' inner struggles as they evolved their thoughts:

> When, after several hours, I came to myself again, I asked myself what it was that had so fascinated me. The answer is simple. The results were not presented as ready-made, but scientific curiosity was first aroused by presenting contrasting possibilities of conceiving the matter. Only then the attempt was made to clarify the issue by thorough argument. The intellectual honesty of the author makes us share the inner struggle in his mind (Einstein 1949b).[64]

In his foreword to the English edition of physicist Louis de Broglie's (1892–1987) book *Physics and Microphysics*[65], which was published in 1955, Einstein used very similar words to emphasize the real experience of the train of thought as the most impressive reading occurrence for him:

> What impressed me most, however, is the sincere presentation of the [inner] struggle for a logical concept of the basis of physics which finally led de Broglie to the firm conviction that all elementary processes are of a statistical nature (de Broglie 1955, p. 7).[66]

The findings in Minor (1984, pp. 17–18), Locke (1992, pp. 107–112), and Heydenreich (2021, pp. 49, 53, 57, 62, and 66) indicate that, in the three scientific writings they examined, Einstein followed his view that the manner of exposition must enable the audience to follow and experience the author's train of thought.[67]

7. Masters of exposition

Einstein admired scientists who were able to expose their results in a highly accessible, comprehensible, and concise manner as masters of exposition. The group of those whom he honored with this accolade is large. In addition to Lorentz, whose expositions Einstein praised

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[62] Published translation (Mach 1893). German original: *Die Mechanik* (Mach 1883).

[63] English original (Cohen, Nagel 1934).

[64] German original in Einstein (1949a): "Als ich nach mehreren Stunden wieder zu mir kam, fragte ich mich, was so fesselnd auf mich gewirkt hatte. Die Antwort ist einfach. Die Ergebnisse waren nicht als etwas Fertiges präsentiert; sondern es wurde die wissenschaftliche Neugier zuerst dadurch erweckt, dass zuerst kontrastierende Auffassungs-Möglichkeiten präsentiert wurden. Dann erst kam der Versuch, durch sorgfältiges Argumentieren die Sache zu klären. Die Ehrlichkeit des Verfassers bringt es mit sich, dass wir den inneren Kampf (struggle) miterleben, der in ihm vorgegangen ist."

[65] Published translation (de Broglie 1955). French original: *Physique et Microphysique* (de Broglie 1947).

[66] German original in Einstein (1955b): "Was mir aber den grössten Eindruck gemacht hat[,] ist die aufrichtige Darstellung des inneren Ringens nach einer konsequenten Erfassung der Basis der Physik, das De Broglie schliesslich zu der festen Überzeugung der statistischen Natur alles elementaren Geschehens geführt hat."

[67] See section 1.2.

for treating the subjects "masterfully" (Einstein 1993, p. 200; 1996a, p. 376)[68], the group included Weyl, whose book *Space–Time–Matter* he called a "symphonic masterpiece" (Einstein 1998c, p. 491)[69] and Weyl himself an "incredible master of exposition" (Einstein 1998c, p. 654).[70] Other masters for him were Schlick, whose publication *Space and Time in Contemporary Physics* he praised as "masterful" (Einstein 1998c, p. 459)[71] and himself as "a true artist of exposition" (Einstein 1998c, p. 707)[72], as well as the physicists Ludwig Boltzmann (1844–1906), whom he called a "masterly expounder" (Einstein 1987b, p. 149)[73], and Mach, who, in Einstein's opinion, wrote "superbly explained thoughts" (Einstein 1997, p. 143)[74] and "effortlessly […] concise and striking sentences" (Einstein 1997, p. 145).[75] Einstein also included the physicist Max Planck (1858–1947), whose books on thermodynamics and thermal radiation he characterized for their "straightforward, truly artistic style," stating that they "belong among the masterpieces of the physical literature" (Einstein 1996b, p. 275).[76] Pauli, whose treatise *Theory of Relativity*[77] Einstein admired as a "mature and broadly conceived work" (Einstein 2012b, p. 80)[78], as well as the physicist Arnold Sommerfeld (1868–1951), whose book *Atomic Structure and Spectral Lines*[79] he praised for being "wonderfully transparent" (Einstein 2006b, p. 337)[80], can also be added to this group.

On the other hand, there were some persons whose expositions Einstein repeatedly reprimanded. Gibbs and Hilbert were already mentioned above. Einstein even criticized his personal friends Zangger and Besso in this respect. In his correspondences with them, Einstein reprimanded Zangger's exposition as "not worded clearly and pointedly enough (not every word is placed clearly and consciously)" (Einstein 1998c, p. 361)[81] and Besso's exposition as "erratic

[68] Translation by the authors. German original in Einstein (1993, p. 200): "Ich zweifle nicht daran, dass [Lorentz] den Gegenstand meisterhaft […] behandelt haben wird."; German original in Einstein (1996a, p. 376): "Im letzten Vortrag sind die Anwendungen der letzteren Theorie auf die Plancksche Strahlungsformel meisterhaft dargelegt."

[69] German original in Einstein (1998b, p. 669): "Die Korrektur Ihres Buches, welche ich bogenweise bekomme, lese ich mit wahrer Begeisterung. Es ist wie eine Meister-Symphonie."

[70] German original in Einstein (1998b, p. 893): "Ich weiss, wie viel leichter es ist, Menschen zu überzeugen, als Wahrheit zu finden, besonders für einen, der ein so unerhörter Meister der Darstellung ist wie Sie."

[71] German original in Einstein (1998b, p. 627): "Die Schlick'sche Darlegung ist meisterhaft."

[72] German original in Einstein (1998b, p. 965): "Sie sind wirklich ein Künstler der Darstellung."

[73] German original in Einstein (1987a, p. 260): "[Boltzmann] ist ein meisterhafter Darsteller."

[74] German original in Einstein (1996a, p. 279): "Dort finden sich Gedanken meisterhaft dargelegt."

[75] German original in Einstein (1996a, p. 281): "Beim Lesen der Machschen Werke fühlt man angenehm das Behagen, das der Autor beim mühelosen Niederschreiben seiner prägnanten, treffenden Sätze gefühlt haben muß."

[76] German original in Einstein (1995a, p. 563), emphasis in original: "Seine Bücher über die Thermodynamik und Wärmestrahlung [gehören] zu den Meisterwerken der physikalischen Literatur […] Das Vergnügen, mit dem jeder diese Bücher immer wieder zur Hand nimmt, ist nicht zum wenigsten auf den schlichten, echt künstlerischen Stil zurückzuführen, der allen Werken *Plancks* eigen ist."

[77] Published translation (Pauli 1958). German original: "Relativitätstheorie" (Pauli 1920).

[78] German original in Einstein (2012a, p. 152): "Wer dieses reife und groß angelegte Werk studiert, möchte nicht glauben, daß der Verfasser ein Mann von einundzwanzig Jahren ist."

[79] Published translation (Sommerfeld 1923). German original: *Atombau und Spektrallinien* (Sommerfeld 1919).

[80] German original in Einstein (2006a, p. 532): "Ihr Buch ist […] von einer wunderbaren Durchsichtigkeit und Schönheit."

[81] German original in Einstein (1998a, p. 495): "Die abstrakten Teile […] scheinen mir vielfach unnötig schwierig (allgemein) gehalten, und dabei nicht klar und scharf genug redigiert (nicht jedes Wort klar und bewusst an die richtige Stelle gesetzt)."

and not well elaborated logically" (Einstein, Besso 1972, p. 290).[82] When Einstein wrote to his biographer Carl Seelig (1894–1962) in 1952 about his relationship with Zangger, he characterized his friend's deficiencies regarding the exposition of his scientific writings as follows: "He saw things clearly and incisively, and [*sic*] his sentences describing them were so hopelessly muddled that one grasped a thought only by reading larger parts and appropriately combining them" (Einstein 1952).[83]

8. Negative role model

Einstein's sharpest reprimands, however, were against Gauss. He regarded Gauss's expositions presenting completed thought constructs not only as negative examples, but also as negative role models. Einstein's comparison of Hilbert's manner of exposition with that of Gauss in a postcard to Ehrenfest in May 1916 makes this very clear. There, in his judgment on Hilbert's exposition, he equated the phrase "not straightforward" and the term "Gauss-like" with a mathematical equals sign: "not straightforward (= Gauss-like)" (Einstein 1998c, p. 213).[84]

In a later statement, Einstein made it more tangibly clear why he disliked Gauss's manner of exposition. In May 1953, Einstein wrote a letter to his friend Maurice Solovine (1875–1958), who translated many of Einstein's writings into French, defending phrases in his 1917 popular booklet *Relativity: The Special and the General Theory*[85]. Solovine regarded these phrases as a violation of the Gaussian exposition ideal, as can be seen in a letter Einstein wrote to his friend. Here, Einstein took up Gauss's well-known dictum, "A good building should not show its scaffolding when completed" (von Waltershausen 1966, p. 67).[86] He considered this view to be counterproductive for a comprehensible exposition of complex thought constructs such as the theories of relativity. Einstein therefore countered Solovine with the counter-dictum that "one cannot build a house or construct a bridge without using a scaffold which is really not one of its basic parts" (Einstein 1987c, p. 147).[87] The scaffolding with which a thought construct had been erected was for Einstein an essential epistemic access aid, which must not be omitted in its exposition, as Gauss had done. Einstein's counter-dictum illustrates very vividly how little he liked to present completed thought constructs to the reader. Epistemic accessibility had priority for him.

[82] Translation by the authors. German original: "Deine Artikelchen habe ich hübsch gefunden, aber etwas sprunghaft und logisch nicht gut durchgearbeitet."

[83] Translation by the authors. German original: "Er sah die Sachen klar und scharf und [sic] seine Sätze darüber waren jeweilen hoffnungslos confus, sodass man einen Gedanken nur erfuhr, indem man grössere Stücke las und passend kombinierte."

[84] German original in Einstein (1998a, p. 288): "Hilberts Darstellung gefällt mir nicht. Sie ist […] unnötig kompliziert, nicht ehrlich (= Gaussisch) im Aufbau (Vorspiegelung des Übermenschen durch Verschleierung der Methoden)."

[85] Published translation (Einstein 1997, pp. 247–417). German original: *Über die spezielle und die allgemeine Relativitätstheorie* (Einstein 1996a, pp. 421–534).

[86] German original in von Waltershausen (1856, p. 82): "Einem guten Bauwerke, pflegte er zu sagen, [dürfe man] nach seiner Vollendung nicht mehr das Gerüste ansehen."

[87] German original in Einstein (1956, p. 128): "Es können eben Begriffe nie aus dem Erlebbaren logisch einwandfrei abgeleitet werden. Aber für didaktische und wohl auch heuristische Zwecke ist solches Vorgehen unvermeidlich. Moral: Wenn man gar nicht gegen die Vernunft sündigt, kommt man überhaupt zu nichts, oder auch, man kann kein Haus und keine Brücke bauen ohne Benutzung eines eigentlich nicht dazu gehörigen Gerüstes."

9. Conclusions

Einstein's statements examined here have provided, in their multitude and variety, insights into his views on scientific writing that significantly exceed, in extent and depth, the insights provided by the approaches pursued so far. This has not only allowed us to identify and classify the views by which he aligned and measured the effect and style of scientific writings in a much more detailed and reliable manner than in former studies. It has also allowed us to reveal previously unnoticed aspects of his views and expectations. The examination has led in detail to the following findings.

Einstein reflected and commented on the effect and style of scientific writings throughout his scientific career. Corresponding statements can be found from the years of Einstein's early publications to the end of his life. His statements are deeply reasoned and clearly phrased. He took the persuasive intent of scientific writings for granted. His views and expectations that the mathematics and exemplifications need to be adjusted to the level of the audience and that the exposition needs to be concise and the phrasing clear and precise conformed to the contemporary writing style. On the manner of exposition, however, he went clearly beyond what his contemporaries perceived as standard. Einstein firmly rejected expositions that were merely presenting completed thought constructs. In his view, they did not allow readers to truly grasp the results. He called for expositions enabling readers to follow—or, even better, to experience—the author's train of thought. Einstein considered revealing the train of thought to be essential for the epistemic accessibility of scientific writings and thus to have persuasive power. He communicated this expectation straightforwardly and emphatically to the scientific community.

10. Future research needs

Findings from the analyses of Einstein's scientific writings cited in section 1.2 indicate that Einstein aligned his own scientific writing with his views and expectations. This concurs with an attitude that Einstein expressed in a letter to his son Eduard (1910–1965) in spring 1930. This letter in part addressed aphorisms that his son had written and recently sent to him. Einstein criticized their exposition and phrasing. He apologized for his harsh criticism by explaining that he in principle was "harsh [...] toward everything on paper" (Einstein 2024b, p. 332).[88]

If Einstein was true to this attitude when it came to his own scientific writing, this suggests that the views and expectations revealed in this study should be found systematically applied to his scientific writings. Unfortunately, however, existing analyses do not confirm whether this is the case. Their findings do not meet the conditions for a generalized statement in this regard. They cover only very few of Einstein's writings[89] and were obtained using methodologically different analytical approaches.[90] Moreover, the analyses were not in all cases based on the original German

[88] German original in Einstein (2024a, p. 622): "Die Sprüchlein hat man mir nach Holland nachgesandt. Ich habe sie zwischen Leiden und Utrecht in der Bahn studiert; sie sind nach meinem Geschmack etwas zu klug und zu wenig natürlich und ursprünglich. Du hast eben einen sehr strengen Vater, streng wenigstens gegen alles Papierene."

[89] There are only two scientific papers by Einstein for which the analyses cited in section 1.2 provide more extensive findings. These are his 1905 papers "On a Heuristic Point of View Concerning the Production and Transformation of Light" and "On the Electrodynamics of Moving Bodies".

[90] Baresich's (1980) findings on audience orientation result from a study comparing the audience orientation of three expositions on the special theory of relativity published by Einstein for different audiences.

Minor's (1984) findings on revealing and experiencing the train of thought result from a study examining the influence of Ernst Mach's (1838–1916) historicocritical reconstructions of scientific trains of thought on Einstein's manner of exposition. Minor analyzed in this context the extent to which Einstein followed Mach's model in his 1905 paper "On the Electrodynamics of Moving Bodies".

texts.[91] A generalized statement in this regard will therefore only be possible when findings from methodologically uniform analyses of the original German texts for a larger sample of Einstein's writings are available for comparison. The authors of this study are already working on such analyses.

Furthermore, it would be highly desirable to compare the findings of this study with the findings of similar studies examining the statements of other German-speaking physicists from the early 20th century or with the findings of studies on the writing style of scientific papers in German-language physics journals of this time. Since no such studies are currently available for either of these comparisons, they must also be left to future research.

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Locke's (1992) findings on persuasive intent, winning the audience's attention, and revealing and experiencing the train of thought result from literary studies of writing in the sciences, including five scientific papers by Einstein.

Johnson Sheehan, Rode's (1999) findings on experiencing the train of thought result from a narrative analysis of Isaac Newton's (1643–1727) 1704 treatise on optics and Einstein's 1905 paper "On a Heuristic Point of View Concerning the Production and Transformation of Light" to determine whether the prevailing assumption that narrative and scientific discourse are incompatible genres applies to the two writings.

Lima *et al.*'s (2018) findings on winning the audience's goodwill and amplifying arguments in Einstein's 1905 paper "On a Heuristic Point of View Concerning the Production and Transformation of Light" result from a metalinguistic analysis based on Michael Bakhtin's (1895–1975) philosophy of language.

Heydenreich's (2021) findings on revealing and experiencing the train of thought result from a narratological examination of Einstein's 1905 paper "On the Electrodynamics of Moving Bodies" analyzing the employed narrative strategies and their epistemic functions.

[91] According to the references of the studies cited in section 1.2, the following have based their analyses of Einstein's scientific writings on published English translations: Baresich (1980), Minor (1984), Locke (1992), and Johnson Sheehan, Rode (1999).

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