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Circulation of Coronavirus Images: Helping Social Distancing?

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Summary: As soon as the SARS-Cov2 disease was recognized by experts to potentially cause a serious pandemic, a three dimensional diagrammatic image of the virus, colored in strong red, conquered public media globally.
This study confronts this iconic virus image with a historic image analysis of 33,000 biomedical articles on coronaviruses published between 1968–2020 and interviews with some of their authors.
Only a small fraction of scientific virus publications entail images of the complete virus. Red as an alarm color is not used at all by scientists who don't aim for a non-scientific public.
Circulation in this case concerns the movement of iconic images from a scientific context into a general public. On the basis of hps-studies on scientific diagrams and especially on color use in scientific diagrams to convey specific messages in public, the paper discusses the role of the claim of public corona-virus diagram as "scientific."
It points at relevant differences between most frequent scientific corona-virus images and the diagrammatic image used in public. Both author- and readerships (in science and public) follow contrasting aims and values. Thus, the images meet non-expert readers for whom the images entail very different – and potentially unintended – meanings then to virus experts.

Keywords: history of virus images, Corona-Virus, Covid-19, colour, color, diagram, image, alarm color

From the very beginning of the Covid-19[1] pandemic, three-dimensional images of the virus stood as symbol for the pandemic. Scientific images of viruses have

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[1] The first name for the pandemic disease was "Coronavirus-disease 2019," in brief "Covid-19."

been around for several decades only. In no epidemic or pandemic have scientific or science-near images of the virus become worldwide visual placeholders for the disease and pandemic as consistently as the diagrams in the case of Covid-19. This was not the case with Ebola, or with the precursors of SARS-CoV-2,[2] the SARS outbreak in 2002–2003, nor with MERS, the Middle Eastern Respiratory Syndrome-Coronavirus epidemic in 2013–2016. The first time a virus was used as a symbol for a pandemic was in the case of AIDS in the late 1980s. In that case other images were initially used to illustrate the pandemic, and to this day the spherical HI virus is not the only symbol of AIDS. Instead, the red AIDS ribbon, representing solidarity, can be found even much more often.

The thesis of this study is that it is not self-explanatory, obvious or compellingly purposeful to use an image originating from the natural science context as a symbol for a pandemic in public media. It might even be detrimental to the socio-political and well-meaning goals behind the dissemination of such an image as a symbol. To be considered are the differences between the context of origin of these images and the context of the targeted audience in which these images circulate. Scientific images are assumed to be neutral towards political positions or goals and not emotionally charged. The effect may be all the more subtle if—or because—they carry implicit values and messages.

Images in scientific and medical contexts are subject to values that have prevailed in recent decades, values that go far beyond neutrality, objectivity and reduction. Signs of the graphic or technical production should be as invisible as possible in the result; in the meantime, a special beauty is required for publication in outstanding journals. The demands described in this way counteract the transport of information and motivations that would actually be relevant to the public, regarding natural qualities of the virus as a mobile, flexible and changing entity and regarding the human interaction with it and in human community. One of the challenges of circulating scientific images in public media is that an image's message is not only dependent of the image itself but also of the context and readership. In each case, in different contexts divergent values will be attached to the exact same images and different associations will be triggered in the respectively different contexts. A scientific image will be understood and associated differently by a community mostly not trained in that discipline than in the community of origin.

From all scientific images produced as images of SARS-CoV-19 only few made it into the public and only certain corona virus images have been cited within the scientific community. What qualifies these few images to become icons of the pandemic? What distinguishes the SARS-CoV-19 images that have been widely disseminated in the public domain from others? What is the (implicit) message of these images and what role does color play? On the basis of the history of scientific images, art historic image analysis and historic media studies the article tries to answer the question: how and to what end do these

[2] "SARS-CoV-2" is the later name given to the virus causing Covid-19. The acronym means "Severe Acute Respiratory Syndrome, coronavirus-2." This distinguishes CoV-2 from the virus causing the SARS pandemic in Asia nearly two decades before.

coronavirus images used in public media match the goal for which their use was intended?

The following section deals with the history of the close relationship between viruses as objects of electron microscopy, which produces them visually, and diagrams, which produce them schematically (all together a typical "experimental system"[3]). As discussed in the second section the scientific diagram shows specific qualities and can work as a tool. Some of these aspects make the scientific diagram very powerful in society—and, when circulating—in public, or they can lead to a mismatching of goals due to the different viewership. The appearance of three-dimensional and polychrome diagrams of coronaviruses is quite recent in the history of coronaviruses. In addition, diagrams of a complete coronavirus (the so-called "virion") are rare in scientific publications on the virus: only one in almost four hundred scientific articles uses such a diagram. Section three reconstructs the history of these diagrams, while section four, on the basis of the original scientific journal articles and interviews, works out what those coronavirus diagrams have in common that circulate in public the most, in contrast to the others: They are three-dimensional and use the color red for the protruding spikes —and their public circulation was intended. Sections five and six try to answer: Are these scientific coronavirus diagrams of high circulation an ideal tool to help advance the media messages on Covid-19 that they illustrate? Section five focuses on the formal aspects of these originally scientific images and section six discusses these images' color red and experiences made with the use of this color in public data image history. Concluding remarks in section seven summarize and sharpen the results.

1. The Diagram's Relation to the Electron Microscopy Image

The knowledge about viruses that would later be called coronaviruses was advanced significantly by progress in electron microscopy. These viruses, just as any other virus, are submicroscopic objects, for they are smaller than the wavelength of light. In order for color to appear, light of any color (i. e., wavelength) needs to be reflected by an object. This is not possible for an object smaller than light's wavelength. The only "microscopic" way to "see" a virus is through electron microscopy. The different methods of electron microscopy developed since the 1930s all have in common that they produce a stream of electron waves (which has a much smaller wavelength than light) which is reflected by the object and can then be recorded.

The diagrammatic representations of the HI virus and SARS-CoV-2 as icons of the respective disease and pandemic date back to the fact that viruses have been displayable in the electron microscope since the 1940s. From then on, diagrams began to be made of them.

Before that, ideas of what a virus was, were vague. Virus is the word for mucus, or poison (in Latin). Up until Robert Koch's famous postulates, "virus" was seen as a disease-causing fluid. Koch then showed in 1882 on the

[3] Rheinberger 1997.

tuberculosis bacterium that pathogens can be caught with filters, namely bacteria, but still viruses remained that passed the filters. Thus they were called unfilterable pathogens. In 1938, a virus member of the smallpox family (which affects mice) was first successfully shown in the electron microscope in the *Wiener Klinische Wochenschrift*, even if only as blurry blotches.[4] This was followed in 1939 by the tobacco mosaic virus and soon thereafter as a continuous coupling of electron microscopic image and diagram of the respective virus. When it comes to the terminology of the virus, the first diagram of a virus seems to be one of bacteriophages (Figure 1), the simplest viruses, infecting bacteria. More complex viruses were drawn in the 1950s, paradigmatically tobacco mosaic viruses, which most closely represent the technical liaison between electron microscopy and virus.[5] With electron microscopy, the virus began to assume a stable reality as an agent.[6] Since their appearance, electron microscopic images have served as evidence that viruses really do exist, and this has always applied to the new types of viruses that have been shown with them. The diagrams, on the other hand, were added mostly when it was necessary to depict viral processes in the cell.[7]

2. A Special Type of Image: The Scientific Diagram

The impressive images that appear in public as portraits of SARS-CoV-19 are diagrams—even though often in their three dimensional looks, strong physicality and light effects they look like photos. For intra-scientific discourse, even for scientists in the "feedback-loop" with their own data,[8] visualization of data is crucial. The role of diagrams is described in the history of science as one of mediation between seeing and thinking. Diagrams organize knowledge. A

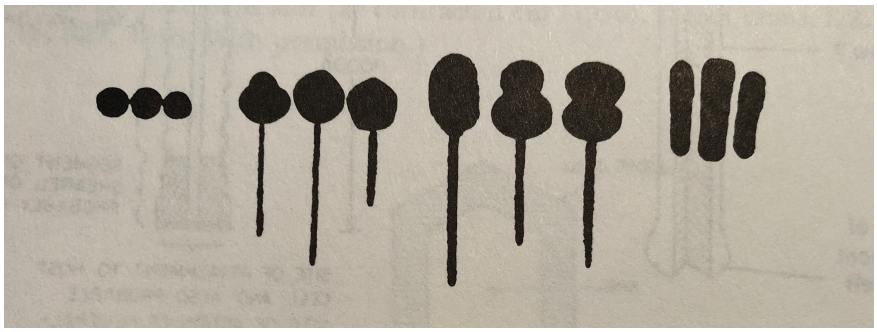


Figure 1. This drawing of bacteriophages is probably the first scientific depictive diagram of entities called "viruses". Ruska 1943, on 437 (with permission).

[4] Borries et al. 1938.
[5] Creager 2002.
[6] Weingart 2004.
[7] Helvoort 2004.
[8] Pyle 2000.

diagram can be understood as a kind of symbolic representation of information.[9] The omission of all unnecessary data in the diagram and the simplified shapes help to easily grasp and use diagrams as placeholders or models for the real object of study[10] so that they can be used as "paper tools"[11] and "working object"[12]without harm and waste of material. Diagrams are easy to transport without changing their form and thus easy to bring close to other circles than their circle of origin.[13] Diagrams appeal to our *Gestalt* perception, and to the ability to recognize patterns. This is an aspect that makes them suitable for educational purposes, including communicating scientific results to the broader public.[14]

A distinction can be made between the image as a representation of a real object, an icon in the sense of Charles Sanders Peirce,[15] and the diagram as an abstract form. The corona virus diagram is both: It is iconic insofar as it is immediately visually graspable as a symbol (of itself, of the now-familiar corona virus diagram) without the detour of a text to be read. At the same time, in their abstract form, diagrams are graphical representations that do not necessarily represent objects, but rather represent invisible properties of objects that are often relational aspects within the objects.

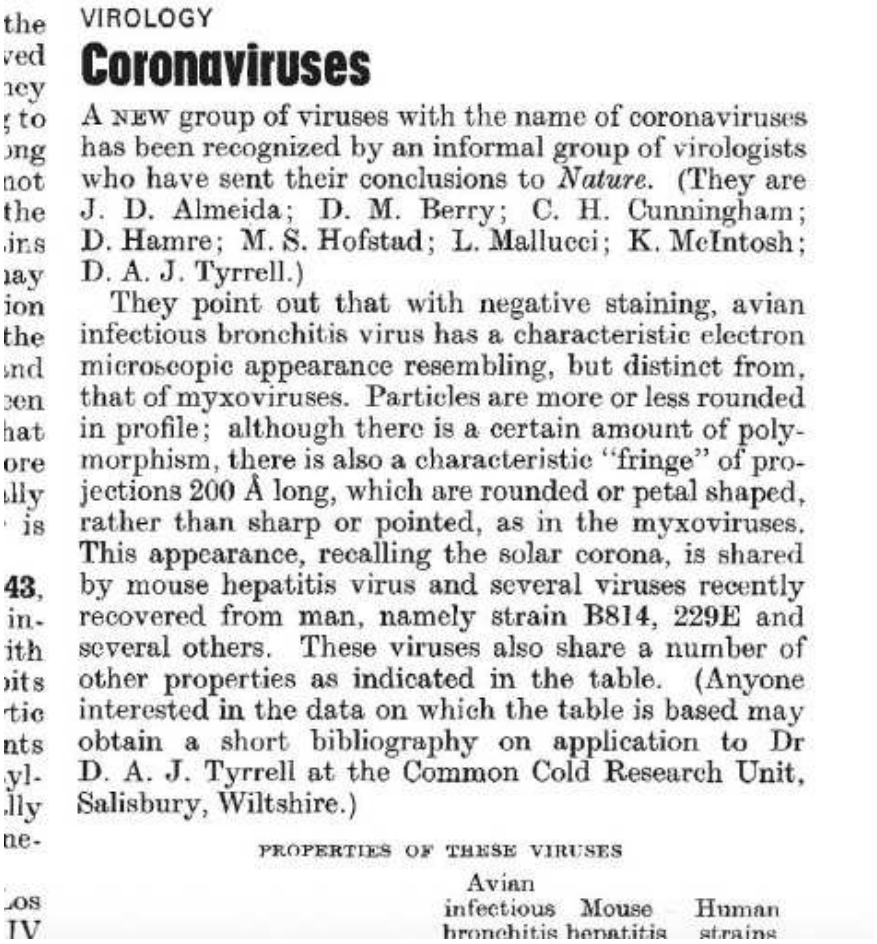
Most scientific diagrams therefore also have a special, complex relationship to the materiality of the reference object. The reductions and aesthetic optimizations, however, can also be seen as a source of distrust,[16] which is why virus diagrams hardly ever appear in the scientific context without the electron microscopic images that legitimate them. In art history, one assigns to images that they always bring with them a surplus that can hardly be tamed, but can also be extra evoked or amplified.[17] Beyond that Georges Canguilhelm even pointed out regarding medical images, especially of pathogens as "ontological representation of sickness," that they entail a mandate for action.[18] This was because of the act of demonstrating that is implicit in the image. Demonstrating means that one has understood the underlying object—resulting in medicine in the call to act. This becomes especially relevant when the scientific image leaves its original thought collective[19] to circulate and meet another collective.[20] While a biomedical image bears a mandate for action for medical scientists or personnel, what will it mean to a non-medically schooled audience?

[9] Kaiser 2009; Woody 2001; Klein 2000; Krohn 1991; Lynch 1991.
[10] Woody 2001.
[11] Klein 2000; e. g., Bock von Wülfingen 2019a.
[12] Daston and Galison 2007; e. g., Engelmann et al. 2022.
[13] Kaiser 2009.
[14] Hand and Choi 2010; Brush 1996.
[15] Pierce 1906.
[16] Lynch 1991.
[17] Bredekamp 2020; Panofsky 1997. For science, see also Rheinberger 1997, on 71.
[18] Canguilhelm 1996, on 12, my translation.
[19] Fleck 1994.
[20] Mößner 2016.

3. Today's SARS-CoV-2 Diagrams and Their History

The first studies of coronavirus-like viruses have existed since the 1950s. These viruses had been discussed together because they caused similar symptoms in animals and sometimes in humans and had a similar aspect in the electron microscopic image.

The term coronavirus was used already in the 1950s. In 1968, a scientific working group proposed to conceptually group different viruses together under the name "corona viruses" (Figure 2).[21] The corresponding article points out the



VIROLOGY

Coronaviruses

A NEW group of viruses with the name of coronaviruses has been recognized by an informal group of virologists who have sent their conclusions to *Nature*. (They are J. D. Almeida; D. M. Berry; C. H. Cunningham; D. Hamre; M. S. Hofstad; L. Mallucci; K. McIntosh; D. A. J. Tyrrell.)

They point out that with negative staining, avian infectious bronchitis virus has a characteristic electron microscopic appearance resembling, but distinct from, that of myxoviruses. Particles are more or less rounded in profile; although there is a certain amount of polymorphism, there is also a characteristic "fringe" of projections 200 Å long, which are rounded or petal shaped, rather than sharp or pointed, as in the myxoviruses. This appearance, recalling the solar corona, is shared by mouse hepatitis virus and several viruses recently recovered from man, namely strain B814, 229E and several others. These viruses also share a number of other properties as indicated in the table. (Anyone interested in the data on which the table is based may obtain a short bibliography on application to Dr D. A. J. Tyrrell at the Common Cold Research Unit, Salisbury, Wiltshire.)

PROPERTIES OF THESE VIRUSES

	Avian infectious bronchitis	Mouse hepatitis	Human strains

Figure 2. Comparison of—then so-called—corona viruses with the fiery celestial body, the sun. Nature 1968, on 650.

[21] Field 1968.

visual similarity of these viruses in the electron microscopic image with the sun and its aureole, which is called the corona.

From then onwards over 33,000 articles on coronaviruses were published and listed in the publication databank *sciencedirect* until end of 2020. Almost all of these articles contain images, many of which are different sorts of graphics. Other often occurring pictures are fluorescence microscopic images, often of lung tissue. Only few of these articles use diagrams of the coronavirus to illustrate their findings.

Out of these 33,000 publications 83 articles contained at least one diagram of a complete coronavirus, either in 2D or in 3D. The first one appeared in 1982 (Figure 3).

The first ten of these diagrams from then on are monochrome black. From 2003 onwards these diagrams begin to come in more colors. Between the years 2003 and 2020 only three diagrams are held in black and white while all others are polychrome. Almost all of these diagrams are accompanied by at least one electron microscopic image of coronaviruses.

Ten of these diagrams began to circulate: These diagrams were cited, i. e., the image reappeared in another scientific article, in a new context (Figure 4).

The original context in which the images were produced and/or appeared were often in or near to the field of structural biology, related to questions of the function and mechanism behind the structure. The new context (article and scientific journal) was not necessarily related to structural biology. Sometimes the diagram was not copied but changed in some aspects (see the change of colors in Figure 3). One of these images that were cited several times circulated beyond the scientific context into the public, as discussed further below.

The authors interviewed share the impression that there is increasing pressure in journal publishing to produce good and that is to say aesthetic images to accompany the text, to draw attention to the text and thus to increase the likelihood of its being read. This is related to the increased competition among the growing number of journals. *Nature*, for example, produces the images itself by its own illustrators, based on the image material sent in by the authors.[22] The interviewees also agree in their impression that these diagrams would be completely ineffective and unattractive today without a halfway modern color composition.

4. Colors of SARS-CoV-2: Red for Social Distancing

Most of the multicolored coronavirus diagrams are in blue or purple. One of the diagrams cited within science (sometimes several times) also reached a public audience. This image, submitted to the journal *The Cell* in an article on the molecular structure of SARS-CoV-2 on 12 July 2020, depicts a three-

[22] Gary Whittaker, interview by the author, Cornell University, USA, zoom, 26 April 2021. He is co-author of Millet and Whittaker 2015.

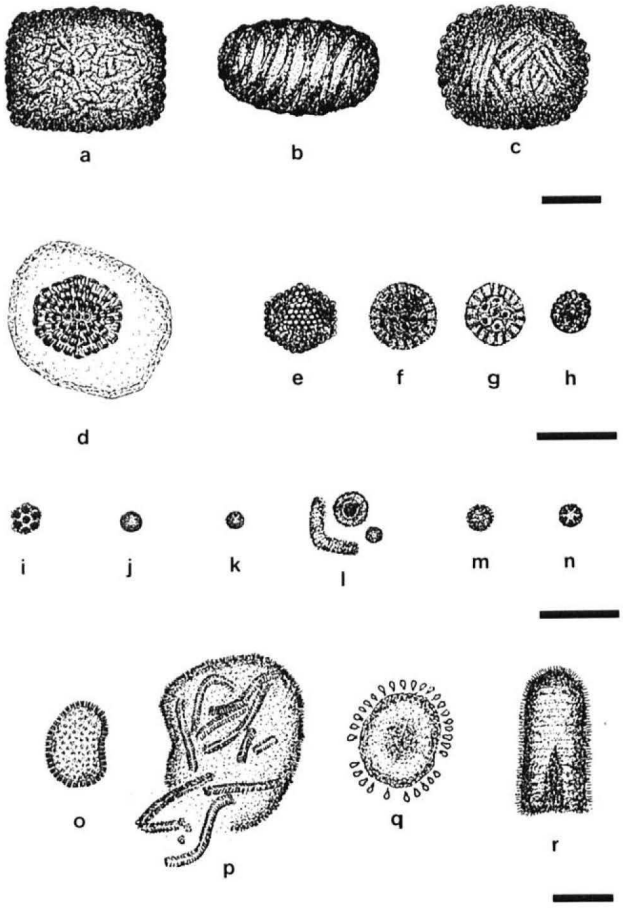


FIG. 1. Systematic morphology: the negatively stained morphology of virus particles represented diagrammatically. a, Orthopoxvirus; b, parapoxvirus; c, molluscum contagiosum virus; d, herpesvirus; e, adenovirus; f, reovirus; g, rotavirus; h, papovavirus; i, calicivirus; j, picornavirus; k, parvovirus; l, hepatitis B antigen; m, Norwalk agent; n, astrovirus; o, orthomyxovirus; p, paramyxovirus; q, coronavirus; r, rhabdovirus. Bars = 100 nm.

Figure 3. The first diagrams on the complete structure of a corona virus appeared in Field 1982, on 69 (with permission). The coronavirus is in the last row (q).

dimensional view of the virus and has attracted much publicity in media.[23] Accompanying the image, an animation was produced that interactively allows the user to turn the virus and see how it is assembled from individual parts. This media material had been produced by a company the author commissioned to do the imaging on the basis of his sketches. The Chinese author, Sai Li, had worked for a long time in Europe, among others, doing his master degree

[23] Among others, it was immediately publicized by *The New York Times*: Zimmer 2020.

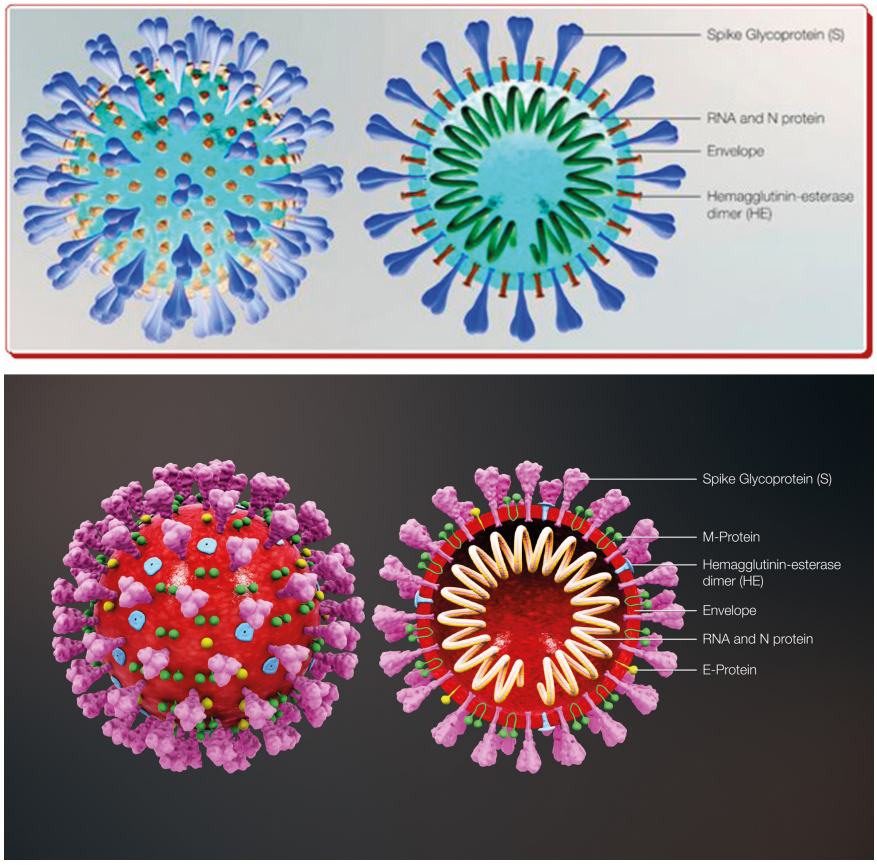


Figure 4. An example of different versions of a coronavirus diagram in different media. On top: Sofi et al. 2020 (with permission); see polychrome original here: https://ars.els-cdn.com/content/image/1-s2.0-S2590053620301142-gr2_lrg.jpg, published online on 8 November 2020, using an unchanged Wikimedia public commons coronavirus diagram held in violet, red and pink. Below: Satheesh et al. 2020 (with permission); see polychrome original here: https://www.cell.com/heliyon/fulltext/S2405-8440(20)32387-2?_returnURL=https%3 A%2F%2Flinkinghub.elsevier.com%2Fretrieve%2Fpii%2FS2405844020323872 %3Fshowall%3Dtrue, online on 19 November, with a structurally similar diagram in dark and light blue.).

in Stuttgart and staying for his doctorate in Göttingen. He has now been back in Beijing for some years at a laboratory where work is being done on vaccine development. Together with his research group he created the templates for this diagram of a three-dimensional SARS-CoV-2 virus with red spikes (Figure 5).

Other than this diagram, of all the more than 80 SARS-CoV-2 diagrams, three diagrams were found that use red for the spikes instead of the colors blue, purple, or green. None of them is in 3D.

Li explained that the only thing about these images where one does not reconstruct the data, where one is free to choose, is the colors. He said that he

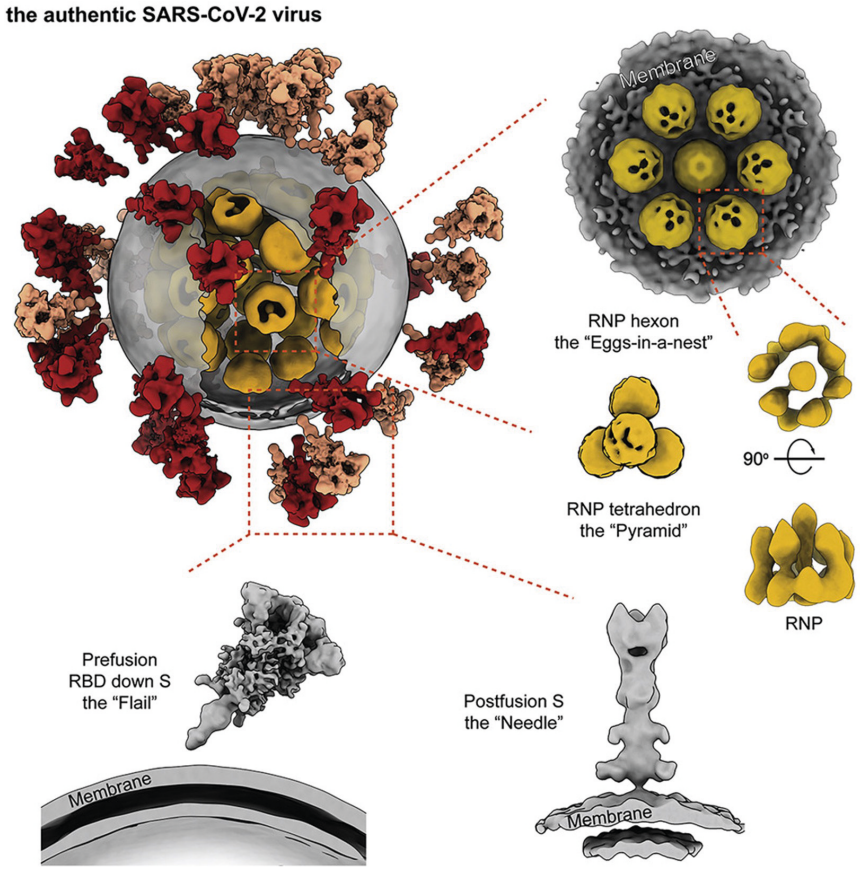


Figure 5. SARS-CoV-2 in 3D with red spikes. Yao et al., on 732 (with permission); see polychrome original here: https://www.ncbi.nlm.nih.gov/core/lw/2.0/html/tileshop_pmc/tileshop_pmc_inline.html?title=Click on image to zoom&p=PMC3&id=7474903_gr1_lrg.jpg.

had first chosen the color ginger-yellow (for the parts in the mid of the virus) because it was his favorite color. But he also had the red in mind from the beginning, even before his work on the virus had even begun: "I wanted it to look threatening, so that it would help politicians to make people stay home. You know that many people don't believe in that it exists, I was thinking of that even before I got the sample [of SARS-CoV-2]."[24] Apparently, the size ratio of the components can be varied additionally, because the volume of the round corpus of the virus in relation to the size of the spikes does not align with that in other diagrams made with the same technique and also not with the electron microscopic pictures. In comparison, these spikes appear very large.

[24] Sai Li, interview by the author, School of Life Sciences, Tsinghua University, Beijing, zoom, 5 March 2021. He is co-author of Yao et al. 2020.

Another SARS-CoV-2 image (Figure 6) that was published on 30 January 2020[25] and immediately circulated in public, did so even much before the structure of the Covid-19 virus had been deciphered and much before the structural diagram by Li and his working group was published. It was an image produced by the US Centers for Disease Control in Washington, explicitly produced on a scientific basis and using the usual scientific tools for rendering (among others, a specific protein databank), and what was known of other coronaviruses.

The scientific illustrators Alissa Eckert and Dan Higgens had been asked in their department at the CDC on 21 January 2020 to produce an image of SARS-CoV-2 for press releases and other media material. It should give the virus an "identity" that would "grab the public's attention."[26]

A month later already *New York Times* author Cara Giaimo called it an "icon," that "saturated news outlets around the world," looming behind every TV news about SARS-CoV-2.[27] Eckert and Higgens stressed that the scientific data behind the image were correct as far as they could be constructed from the current knowledge on SARS-CoV-2 and data on the protein structure of other coronaviruses. These scientific illustrators aimed at a pleasing "beauty shot."[28] At the same time, however, said Alissa Eckert in another interview the spikes should be red to indicate dangerousness:[29] The image was designed to

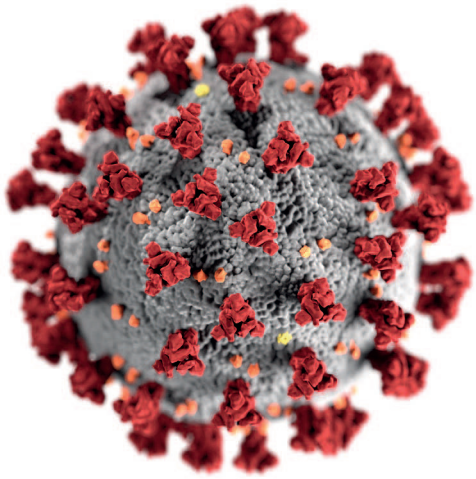


Figure 6. The first scientific picture of SARS-CoV-2 to be circulated immediately worldwide, especially outside the scientific media. Eckert and Higgins 2020; see polychrome original here: https://phil.cdc.gov/Details.aspx?pid=23313.

[25] Eckert and Higgins 2020.
[26] Eckert and Higgins, quoted in Giaimo 2020.
[27] Giaimo 2020.
[28] Eckert and Higgins, quoted in ibid.
[29] Frumkin 2020.

convey "a feeling of alarm."[30] A *New York Times* illustrator called the CDC's depiction of the virus "sinister,"[31] another author called it "creepy."[32] This aspect is not only caused by the decision to give the spikes the color red, but this paired with the avoidance of (other) bright colors accompanied by the use of gray, to convey solemnity, added to an aspect of texture for the round "body" of the virus that suggests a haptic physicality.[33] Art critic Philip Kennicott, in an interview with journalist Rebekah Frumkin, expressed his impression of the CDC diagram of SARS-CoV-2, as "clearly emphasizing the threat this virus poses to those who refuse to, or cannot, socially distance themselves."[34]

5. The Power of Circulating Virus Images in Science and Society

In the course of the 1980s, a virus was for the first time set as a synecdoche, a pars-pro-toto for the corresponding disease.[35] Similar to the way the DNA double helix became a global visiotype,[36] i. e., at the same time a scientific concept and a cultural icon, images of HIV became a stand-in for all topics related to AIDS from the mid-1980s on (Figure 7). The image was recognized worldwide, following a "code of visualization that has become intertextual, international and culturally compulsory."[37]

In its globally iconic role, the first electron microscopic images of HIV, subsequently colored, were replaced in 2010 by a diagram resulting from an international competition hosted by the journal Science together with the US Science Foundation (Figure 8).[38] It is easy to see that the icon of Covid-19 follows the diagram of the HI-virus in terms of its style and aesthetics. Apart from different shades of gray here though, light and dark orange were applied.

However, it was a long way to the first pictures of the HI virus, because from the beginning of the work on it in 1981 until the virus clarification in 1984 it was completely unclear what the actually triggering virus was and what accompanying physiological effects and symptoms. During this period of ambiguity, the diagnosis of AIDS near to always included the scientific description of the patient as a "homosexual man." The image of the HI virus therefore replaced in the illustration of AIDS the patient emaciated by disease with the black bar over the eyes, as paradigmatic in medicine as in criminology, as well as such illustrations that depicted maps of the regions where AIDS was

[30] Higgins, quoted in Fairs 2020.
[31] Frumkin 2020.
[32] Davis 2020.
[33] Giaimo 2020. See also Hattam 2021.
[34] Kennicott, quoted in Frumkin 2020.
[35] Weingart 2004, on 134.
[36] Uwe Pörksen 1997, on 27.
[37] Rosello 1998, on 383.
[38] Konstantinov 2010.

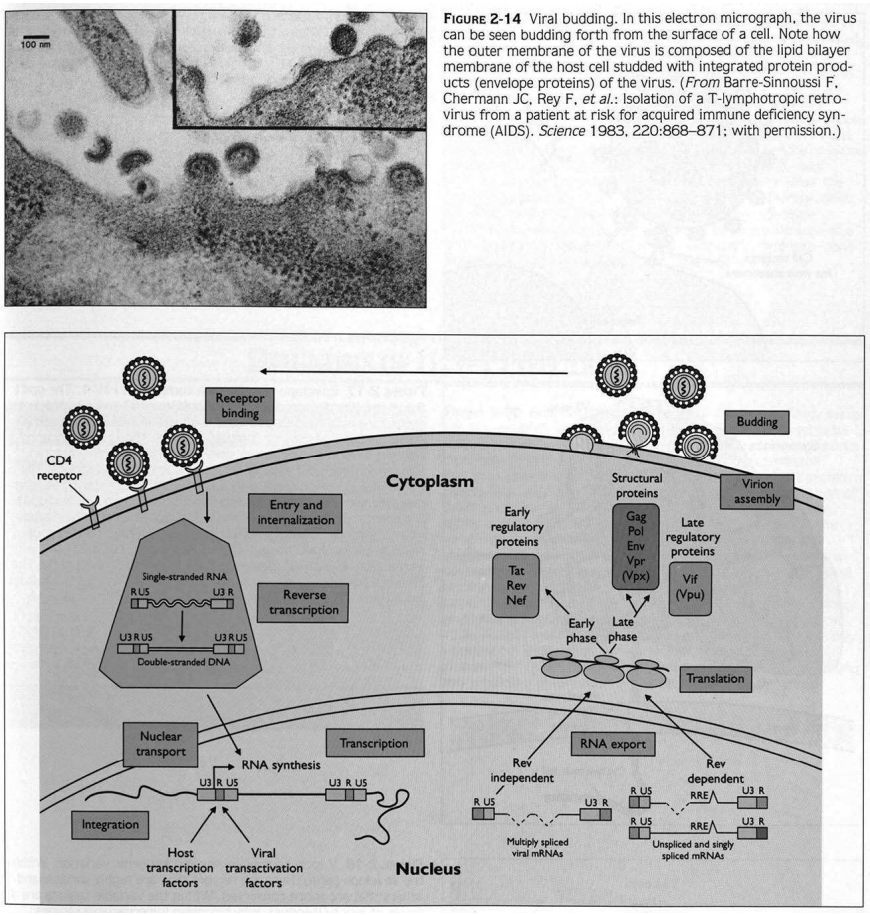


FIGURE 2-14 Viral budding. In this electron micrograph, the virus can be seen budding forth from the surface of a cell. Note how the outer membrane of the virus is composed of the lipid bilayer membrane of the host cell studded with integrated protein products (envelope proteins) of the virus. (*From* Barre-Sinnoussi F, Chermann JC, Rey F, *et al.*: Isolation of a T-lymphotropic retrovirus from a patient at risk for acquired immune deficiency syndrome (AIDS). *Science* 1983, 220:868–871; with permission.)

Figure 7. A typical and also in public often quoted HIV picture was published in an atlas on HIV by Mildvan 1995, on 23, Figure 2.1 (with permission). The picture itself in the upper part cites one of the first electromicrographs of 1983 that were scientifically agreed upon to depict the AIDS virus.

prevalent—often certain, "homosexually relevant," precarious urban areas.[39] In the face of such stigmatizing imagery, the image of the virus had several advantages: it established, in an environment of denial, the undeniable materiality of the virus; it seemed purged of social, cultural, or political meanings and was an icon of a neutral, value-free natural science way of seeing the pandemic; and it bore the insignia of natural science in action.[40] Thus, to refer back to Canguilhelm, the natural science image of the virus carries a promise of a solution.

[39] Engelmann 2018.
[40] Ibid.

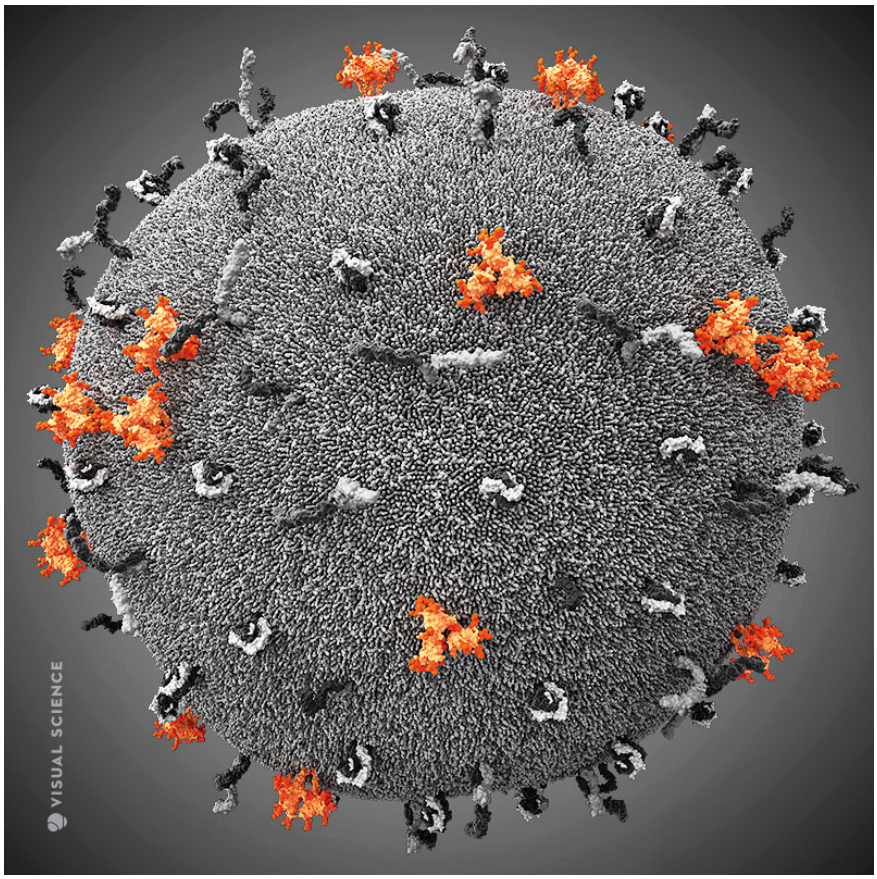


Figure 8. Rendered diagram of HI virus. Konstantinov and Visual Science 2010 (with permission); see polychrome original here: http://static.208.15.99.88.clients.your-server.de/projects/hiv/illustrations/.

At least four aspects justify that the image of the HI virus could become a worldwide icon across disciplines and in the public,[41] which also apply to the image of the CDC and its early successors: when images of viruses and bacteria enter the world before they have been understood and classified, this lack of knowledge allows the object to be iconically equated with everything that is to be (medially) transported and associated with it. Second, the object in the scientific image appears as a discovered natural object, even if, for example, the electron microscopic image is based on conventions and elaborate experimental procedures.[42] Moreover, the image unites the scientific community around this object. However, it is also suitable for public use, both for science and for public health and campaigning in general, for the reasons mentioned above,

[41] Ibid.

[42] Rheinberger 1997.

especially because of the apparent neutrality imputed to the scientific image. Furthermore, values and conventions in the natural sciences and especially in virus research force the authors of virus diagrams to represent corona viruses in certain ways, which remove these diagrams far from the reality of the viruses represented in the EM image. These values then do not serve a potential purpose of elucidation with regard to properties of the virus that are particularly relevant to the public. These values imposed by scientific publishing on the virus diagrams are simplicity and beauty.[43] The rising pressure to produce beautiful pictures and to use the digital options to do so is also object of discussion in the science journals themselves for some years.[44]

In contrast to the diagram of the always single virus in front of a black or white background, on electron microscopic images (corona) viruses hardly ever appear alone. It is the clustered occurrence that increases the likelihood of gene exchange between contiguous viruses, resulting in new virus variants. A single virion, in contrast, suggests that it was manageable. In addition, an average ideal virus is created from many pleomorphic viruses (some are flat, some are worm-like, some are oval) in a lengthy computer process, which then results to be perfectly round.[45] This also promotes the impression of statics, instead of lively movement—and thus controllability again. Last but not least, the iconic coronavirus diagram represents the virion in the phase when it has left the host body or is on its way to do so. The phase of several days of eclipse, in which the coronavirus has reached the cells and is broken down into its individual parts, is thus neglected.

By these omissions the virus does not appear part of the human host, which it is about half of the time of its existence. The individual's role as potential ignorant transmitter may be immediately clear to every bio-scientist with the image of the virion. However, when the virion image is brought into the public context, it tends to endorse an anthropocentric human image of bodily integrity[46] rather than acknowledging that much of the human biomass is not of human origin.[47] What is missing is a facet of a virus picture that shows us human individuals as potential carriers of the virus precisely because the virus has, in only few years of virus "evolution," become able to make itself common with our body, because it thus becomes a part of us, like so many viruses and bacteria that live with us—in and on us—anyways. In the assumption of a clear boundary between inside and outside, the virus instead becomes the "enemy from outside" (and therewith follows a long cultural tradition to treat contagions as alien and foreign warriors).[48] What this blurs is an overall social

[43] Gary Whittaker, interview by the author, Cornell University, USA, zoom, 26 April 2021; Sai Li, interview by the author, School of Life Sciences, Tsinghua University, Beijing, zoom, 5 March 2021; Jai Prakash, interview by the author, Department of Biomaterials Science and Technology, Twente University, Netherlands, zoom, 6 May 2021 (Prakash is co-author of Heinrich et al. 2020); Buriak 2016; Marx 2002.

[44] E.g., Pearson 2005; Peterson 2005.

[45] Whittaker, interview by the author, Cornell University, USA, zoom, 26 April 2021.

[46] Löwi 1991.

[47] See Haraway 1991.

[48] Wald 2020; Wald 2008; Weingart 2004.

responsibility in dealing with the human-nature relationship inside the individual and in the external environment. Many aspects of what was said above could be easily remedied by, e.g., using the mouth-nose mask as a pars-pro-toto for this pandemic instead of a "rendered" coronavirus in public. This comparison reveals that the call to action communicated in the picture[49] would be a completely different one: the mask calls for protection of oneself and others. The coronavirus diagram, on the other hand, in contrast to what its use in public aims at, refers to virological expertise and thus relieves the reader of responsibility and of the need for action.

Other alternative iconic representations of the pandemic were proposed and brought to mind in the early months of the pandemic: some artistic representations of the corona pandemic emphasized the aspect of community threat and effort.[50] Here, the call in the paintings would be "we need each other, cooperate." Others, such as historical paintings and graphics of plague and cholera, showed powerlessness of the individual, mass suffering and socio-economic misery.[51] What these images communicate is "look at this misery"—but also that politics is called for, and possibly world politics when the plague is sweeping through Europe in Bruegel's time.

6. The Tragedy of the Color Red in Scientific Data Images

Colors trigger emotions.[52] So much so that European history of science shows phases of stigmatization of color as directly appealing to emotions. Color has long been seen as in conflict with cognition, intellectual creativity, and scientificity. These qualities, on the other hand, were commonly assigned to text and graphics originally in black and white.[53]

Colors were found in scientific illustrations primarily in mimetic illustrations, where natural objects were to be imitated in the picture. The role of color in diagrams, on the other hand, may be to stand as another operator alongside other graphic signs (i.e., as another distinguishing feature that possibly embraces different graphically distinguished categories).[54] Color is able to structure an image in all directions or even in three dimensions without the need to add further shapes.[55] Nevertheless, color can also carry additional meaning. The use of color can also make the Gestalt aspect of the image more explicit. Thus, color can increase the epistemic and pedagogical utility of diagrams. One of the few fields of natural science for which rich historio-

[49] Canguilhelm 1996.
[50] Carusi 2020; Chatterjee 2020.
[51] Rossi 2020.
[52] Pastoureau 2007. See also Schneider 2016.
[53] Batchelor 2000; Boskamp 2019; Nagel 2019; Ramharter 2019; Daston and Galison 2007.
[54] Pierce 1933.
[55] Bock von Wülfingen 2019a.

graphical analyses of the symbolic use of color are available is cartography.[56] In cartography, color was used primarily for decoration, distinguishing, and highlighting (red in particular) until the early nineteenth century. A semiotic use of color appeared in geognostic maps in the nineteenth century.[57] While muted and pastel colors were common in scientific and technical representations in the nineteenth century and well into the twentieth century,[58] primary colors (re)entered the scene of technical-scientific images in the 1920s with the impetus of the Bauhaus.[59] As color printing became cheaper and cheaper in new printing processes, color illustrations proliferated since the 1990s and the color spectrum in images in scientific journals increased,[60] as is also reflected in the history of coronavirus diagrams. This is all the more true for scientific online publications since the 2000s.

A major difference between the diagrams of Covid-19, which were poorly cited and remained within scientific disciplines, and those that were disseminated to the public, is the extensive use of the color red in the depiction of the virus. Historically red was the color of authority. It doesn't occur much in nature, was difficult to produce and was a correspondingly expensive color, reserved only for the highest in status. This was lost with the possibility of producing all colors cheaply from tar slag at the end of the nineteenth century. From about the same time comes the redesignation of red to a symbol of danger.[61] From sea signs, red migrated to railroad and then road signs, signaling a prohibition intended to protect against danger. Danger previously had yellow connotations; we still find it on labels on vessels containing toxic chemicals. Elsewhere, however, red replaced yellow for danger in the course of the twentieth century and became *the* alarm color.

A well analyzed case of images crossing from science to public and bearing strong red tones to alarm readers are images related to the topic of climate, such as climate maps and temperature curves. The first figure to popularize the visualization of global warming in climate history is a graph published by Michael E. Mann and his colleagues in 1998 and 1999, first in nature and then in the Geophysical Research Letters. Using tree ring data, they reconstructed mean temperatures from the year 1000 up to today with a strong rise in temperature since the 1850s (the so called hockey stick graph). In the 1999 publication, in the scientific journal, the colors of the first part of the graph were held in yellow and the rise from 1850 onwards in red. For a publication of the same image in a policy report produced for the United Nation Intergovernmental Panel on Climate Change (IPCC)[62] the authors (Mann was one of the co-authors) sharpened the contrast between tempera-

[56] Moser and Meier 2019. For an overview of the role of color in natural sciences, see Karliczek 2018; Bushart and Steinle 2015; Hentschel 2014; Baker et al. 2015.
[57] Palsky 1996.
[58] E.g., Friedmann 2019.
[59] Bock von Wülfingen 2019a.
[60] Palsky 1996; Bock von Wülfingen 2019a and b.
[61] Pastoureau 2017, on 144–151, 176–180.
[62] Houghton et al. 2001.

tures by using blue for the lower part of the curve, keeping the rise in red. Growing popular fast, the image was used by activists, politicians and newspapers as well as in popular science publications on climate change.[63] In a theoretical analysis of this and other charts in the IPCC Lynda Walsh demonstrated how the images, in contrast to the more scientifically oriented text around them, use symbolism to convey narratives of fear. The authors thereby turned into "political scientists,"[64] blurring the boundaries between the respective value system (science: description of facts and causes, politics: value and call to action).[65] Another diagram that was intended to be added to the IPCC report was the so-called "burning ember" bar chart. It summarizes increase of risk of certain critical changes in the context of climate change, using colors ranging from white (no risk) to dark red (ember, highest risk). Instead of including this image, after much political debate and because of the alarming character of the chart, the authors of the report chose to only describe risks non-visually in the text.[66]

A third example is the world heat map analyzed by Birgit Schneider.[67] In an empirical study Schneider and Nocke[68] changed the color-coding in the famous earth heat map, that was part of a later report of the before mentioned IPCC[69]. The original map shows temperature changes between the years 1901 to 2012 in colors from light blue (decrease, this is only a small fraction on the map) over orange tones (beginning with increases of 0 to 0,2 degrees) and red to dark purple (highest temperature increase). Schneider and Nocke produced different images based on the same map, changing colors, among others, using more green or changing it to a yellow-and-red-scale and presented it to test persons. They found that participants of their study saw the original map as most "alarming," "judgemental," and at the same time "discouraging," giving them a feeling of "powerlessness" and "fear."[70] They valued an alternative map in a scale of tones of blue, yellow and red with stronger yellow tones and more nuances as more readable, politically constructive and empowering. The way such climate images are designed, rather than depicting temperature, they take on a role as "a mission statement of concern."[71]

The use of red for warm regions of the world and blue for cold zones in maps goes back to the nineteenth century and can be related to the perceptual impression of water in nature as—usually—cold and red for fire as hot, even the wavelength of blue and red seem to support this meaning as a natural given. This would be consistent with the recommendation in information

[63] Schneider 2014.
[64] Walsh 2007, on 35, 42.
[65] Walsh 2007; Schneider 2014. On the issue of scientific activism, see Carrier forthcoming.
[66] Mahony and Hulme 2012.
[67] Schneider 2018; Schneider 2016; Schneider 2014.
[68] Schneider and Nocke 2016.
[69] Pachauri and Meyer 2014, working group I.
[70] Schneider and Nocke 2018, on 297–298.
[71] Schneider 2014, on 191.

design to apply colors consistent with their natural occurrence.[72] Colors, as discussed above, carry several meanings, so that red is intuitively accompanied by the association of danger.[73] This will be even more true for the coloring of something like the coronavirus, where no connection to temperature can be drawn.

7. Conclusions

Scientific images are very powerful messengers and at the same time held to be neutral and truth telling. Diagrams of viruses gained this validity in the community of science by their continuous company with electron microscopic images they seem to have as their referents. The HI virus was the first to gain worldwide publicity as an icon of a pandemic. Its massive use, replacing earlier discriminatory icons of the pandemic justified the HI virus diagram as seemingly neutral and demonstrative of progress in science. The coronavirus diagram used in public in contrast didn't replace any earlier problematic images. It was the icon of the pandemic before most people on the globe even learned about it, so that this icon, without any competitive alternatives, and without much discussion, stood for any news item in the context of the pandemic—not lending itself easily to illustrate differences in death rates, discrepancies in housing or other socially relevant aspects connected to the corona pandemic.

Diagrams of coronaviruses are nothing typical to virology or other sciences working on viruses. Only few scientists need diagrams of complete coronaviruses in 2D or 3D in their work, so that only one of four hundred publications, mainly in structural and/or molecular biology, show such images. The neat and symmetrical scientific coronavirus diagrams and ever more beautiful color images of the coronavirus are read by scientists as extrapolations of very different virus aspects in the living environment. In the context of a non-biomedical public this information is hidden. The image has to speak for itself, resulting in very different information. This is part of the excess of any image. The virus then seems static and domesticated by virology (in the sense of Canguilhelm) while at the same time, bearing red color in public images, alarming the onlooker. In contrast to the (seldom) complete coronavirus diagrams in scientific publications, those that were intended to leave that context to circulate massively in public were in 3D and used pronouncedly red tones for the spikes—later coronavirus icons in public just tinted the complete virus in red or even in glowing and fiery ember, when it came to the first variants of SARS-CoV-19.

For the use of red for viruses, it is even more true that this color use cannot be explained with a natural link between virus and color, so that only the meaning of alerting remains. When scientists and designers at the CDC as well as scientists working on the coronavirus envision public use of their image,

[72] Tufte 1990, on 90.

[73] Pastoureau 2017; Schneider 2014, on 192.

they have in mind a different, broad and not necessarily scientifically trained audience. This pathway of circulation from science to public changes the image-context-relationship in at least two ways: By having in mind a broader public, the intention of the originally scientific image and the use of scientific image making tools changes: The mission of the image is not so much to transmit facts, but it is a public and political mission (and be it self-imposed as in the case of the scientist's use of red on the virus), which is to turn the image into a tool to support the politics of social distancing. The perspective of the image production moves from the transmission of factual information to transferring value and emotion, more concretely fear—and maybe, even though unsuccessful, to signify a call to action. Will this work in the non-scientific context of the image? We assume that public readers of the image may not read this call to action from the image of the red coronavirus for the reasons given above: the scientized diagram of the virus invokes that what is needed here is scientific expertise, more concretely, of virology. As the image of the virus already exists, apparently the problem is almost solved (by virology) which means that there is an inherent action task—which then would be directed to experts of virology. The image points to something that is beyond the capacities of a non-scientifically trained person. In addition, to see the virus as the problem and enemy, does not help instilling a feeling of responsibility of the individual towards and in community and nature. Finally, to alarm and instill fear by coloring the per se invisible and colorless virus red, evokes panic and helplessness and closes down emotional pathways that may lead to empathy, solidarity, and collaboration.

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References

Ackermann, Hans-Wolfgang, and Laurent Berthiaume, *Atlas of Virus Diagrams* (Boca Raton, FL: CRS Press, 1995).

Altmann, Jan, "Färbung, Farbgestaltung und früher Farbdruck am Ende der Naturgeschichte," in *Farbstrategien*, Bildwelten des Wissens, vol. 4/1, ed. Vera Dünkel (Berlin and Boston: De Gruyter, 2006), 69–77.

Baker, Tawrin, Sven Dupré, Sachiko Kusukawa, and Karin Leonhard, "Early Modern Color Worlds," *Early Science and Medicine* 20, no. 4–6 (2015): 289–591.

Batchelor, David, *Chromophobia* (London: Reaktion Books, 2000).

Bennewitz, Ingrid, and Andrea Schindler, *Farbe im Mittelalter: Materialität—Medialität—Semantik* (Berlin: Akademie Verlag, 2011).

Bock von Wülfingen, Bettina, "The Periodic Tableau: Form and Colors in the First 100 Years," *Centaurus: International Journal of the History of Science and its Cultural Aspects* 61, no. 4 (2019a), special issue: *The Periodic System as an Icon in Chemistry and a Typology of Science*, ed. Annette Lykknes and Brigitte van Tiggelen, 379–404.

Bock von Wülfingen, Bettina, "Diagrammatic Traditions: Color in Metabolic Maps," in *Color: Visualizing Achromatic Knowledge*, ed. Bettina Bock von Wülfingen (Berlin and New York: De Gruyter, 2019b), 195–218.

Borries, Bodo von, Ernst Ruska, and Helmut Ruska, "Bakterien und Virus in Übermikroskopischer Aufnahme," *Klinische Wochenschrift* 17, no. 27 (1938): 921–925.

Boskamp, Ulrike, "Color as the Other? Absence and Reappearance of Chromophobia in Eighteenth-Century France," in *Color: Visualizing Achromatic Knowledge*, ed. Bettina Bock von Wülfingen (Berlin and New York: De Gruyter, 2019), 33–50.

Bredekamp, Horst, "Symbiose von Bild und Natur: Überlegungen zum Neomanierismus," in *Bilder als Denkformen: Bildwissenschaftliche Dialoge zwischen Japan und Deutschland*, ed. Yasuhiro Sakamoto, Felix Jäger, and Jun Tanaka (Berlin: De Gruyter, 2020), 145–166.

Brush, Stephen G., "The Reception of Mendeleev's Periodic Law in America and Britain," *Isis* 87 (1996): 595–628.

Buriak, Jillian M., "Table of Contents Images: Science and Beauty = Clarity," *Chemistry of Materials* 28 (2016): 1589–1590.

Bushart, Magdalena, and Friedrich Steinle (eds.), *Colour Histories: Science, Art, and Technology in the 17th and 18th Centuries* (Berlin and Boston: De Gruyter, 2015).

Canguilhelm, Georges, *Le normal et le pathologique*, 6th edn. (Paris: PUF ("Quadrige"), 1996; first published in 1943 as *Essai sur quelques problèmes concernant le normal el le pathologique*).

Carrier, Martin, "What Does Good Science-Based Advice to Politics Look Like?," *Journal for General Philosophy of Science* 53.1 (2022): 5-21.

Carusi, Annamaria, "Things and Trends: Images of Covid-19," *Medical Humanities*, 22 April 2020, online: https://blogs.bmj.com/medical-humanities/2020/04/22/things-and-trends-images-of-covid-19/ (accessed 25 July 2023).

Chatterjee, Sria, "Making the Invisible Visible: How We Depict Covid-19," *LSE Covid-19 Blog*, 30 June 2020, online: https://blogs.lse.ac.uk/covid19/2020/06/30/making-the-invisible-visible-how-we-depict-covid-19/ (accessed 25 July 2023).

Creager, Angela N. H., *The Life of a Virus: Tobacco Mosaic Virus as an Experimental Model, 1930–1965* (Chicago: University of Chicago Press, 2002).

Davis, Ben, "Why the Centers for Disease Control's Creepy Illustration of the Coronavirus Is Such an Effective Work of Biomedical Art," *Artnet News*, 1 April 2020, online: https://news.artnet.com/ (accessed 25 July 2023).

Dünkel, Vera (ed.), *Farbstrategien*, Bildwelten des Wissens, vol. 4/1 (Berlin and Boston: De Gruyter, 2006).

Eckert, Alissa, and Dan Higgens, "Covid-19," *Public Health Image Library*, 2020, online: https://phil.cdc.gov/Details.aspx?pid=23313 (accessed 25 July 2023).

Engelmann, Lukas, *Mapping AIDS: Visual Histories of an Enduring Epidemic* (Cambridge, MA: Cambridge University Press, 2018).

Engelmann, Lukas, "#Covid19: The Spectacle of Real-Time Surveillance," 6 April 2020, *COVID-19 Perspectives*, online: https://blogs.ed.ac.uk/covid19perspectives/2020/04/06/covid19-the-spectacle-of-real-time-surveillance-writes-dr-lukas-engelmann (accessed 25 July 2023).

Lukas Engelmann, Caroline Humphrey, and Christos Lynteris (eds.), *Working with Diagrams* (Oxford and New York: Berghahn Books, 2022).

Fairs, Marcus, "Iconic Covid-19 Images Designed to Create 'A Feeling of Alarm' Aays CDC Medical Illustrator Dan Higgins," *dezeen*, 14 May 2020, online: https://www.dezeen.com/2020/05/14/covid-19 (accessed 25 July 2023).

Field, Anne M., "Diagnostic Virology Using Electron Microscopic Techniques," *Advances in Virus Research* 27 (1982): 1–69.

Fleck, Ludwik, *Entstehung und Entwicklung einer wissenschaftlichen Tatsache* (Frankfurt am Main: Suhrkamp, 1994).

Friedmann, Michael, "Coloring the Fourth Dimension? Coloring Polytopes and Complex Curves at the End of the Nineteenth Century," in *Color: Visualizing Achromatic Knowledge*, ed. Bettina Bock von Wülfingen (Berlin and New York: De Gruyter, 2019), 51–64.

Frumkin, Rebekah, "How to Draw the Coronavirus," *The Paris Review*, 18 May 2020, online: https://www.theparisreview.org/blog/2020/05/18/how-to-draw-the-coronavirus/accessed 25 July 2023).

Gage, John, "Color in Western Art: An Issue?," *Art Bulletin* 72, no. 4 (1990): 518–541.

Gage, John, *Color and Meaning: Art, Science and Symbolism* (Berkeley: University of California Press, 1999).

Giaimo, Cara, "The Spiky Blob Seen Around the World: How C. D. C. Medical Illustrators Created the Coronavirus Pandemic's Most Iconic Image," *The New York Times*, 1 April 2020, online: https://www.nytimes.com/2020/04/01/health/coronavirus-illustration-cdc.html (accessed 25 July 2023).

Hand, Brian, and Choi Aeran, "Examining the Impact of Student Use of Multiple Modal Representations in Constructing Arguments in Organic Chemistry Laboratory Classes," *RISE* 40, no. 1 (2010): 29–44.

Haraway, Donna, "Biopolitics of Postmodern Bodies," in *Simians, Cyborgs, and Women: The Reinvention of Nature*, ed. Donna Haraway (New York: Routledge, 1991), 203–230.

Hattam, Victoria, "Visualizing the Virus," *Design and Culture* 13, no. 1 (2021): 9–17.

Heinrich, Marcel Alexander, Byron Martina, and Jai Prakash, "Nanomedicine Strategies to Target Coronavirus," *Nano Today* 35 (2020): 100961, DOI: https://doi.org/10.1016/j.nantod.2020.100961.

Helvoort, Ton van, "History of Virus Research in the 20th Century: The Problem of Conceptual Continuity," *History of Science* 32 (1994): 185–235.

Helvoort, Ton van, "Viren, Wissenschaft und Geschichte," in *Virus! Mutationen einer Metapher*, ed. Ruth Mayer and Brigitte Weingart (Bielefeld: transcript Verlag, 2004), 61–78.

Hentschel, Klaus, "Verengte Sichtweise: Folgen der Newtonschen Optik für die Farbwahrnehmung bis ins 19. Jahrhundert," *Farbstrategien*, Bildwelten des Wissens, vol. 4/1, ed. Vera Dünkel (Berlin and Boston: De Gruyter, 2006), 78–89.

Hentschel, Klaus, *Visual Cultures in Science and Technology: A Comparative History* (Oxford: Oxford University Press, 2014).

Houghton, John T., et al. (eds.), *Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge and New York: Cambridge University Press, 2001).

Pachauri, Rajendra K., and Leo A. Meyer (eds.), *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (Geneva: IPCC, 2014).

James, Liz, "Color and Meaning in Byzantium," *Journal of Early Christian Studies* 11, no. 2 (2003): 223–233.

Jameson, Frederic, "Reification and Utopia in Mass Culture," *Social Text* 1 (1979): 130–148.

Kaiser, David, *Drawing Theories Apart: The Dispersion of Feynman Diagrams in Postwar Physics* (Chicago: University of Chicago Press, 2009).

Karliczek, André, "Zur Herausbildung von Farbstandards in den frühen Wissenschaften," *Ferrum* 90 (2018): 36–49.

Kessler, Herbert, "Pictures Fertile with Truth: How Christians Managed to Make Images of God without Violating the Second Commandment," *Journal of the Walters Art Gallery* 49/50 (1991/92): 53–65.

Kessler, Herbert, *Seeing Medieval Art: Rethinking the Middle Ages* (Peterborough, ON: Broadview Press, 2004).

Klein, Ursula, "Berzelian Formulas as Paper Tools in Early Nineteenth-Century Chemistry," *Foundations of Chemistry* 3, no. 7 (2001): 7–32.

Konstantinov, Ivan, and Visual Science, "Human Immunodeficiency Virus (HIV)," 8 September 2010, online: https://visual-science.com/ (accessed 25 July 2023).

Krohn, Roger, "Why Are Graphs So Central in Science?," *Biology and Philosophy* 6, no. 2 (1991): 181–203.

Kuehni, Rolf, and Andreas Schwarz, *Color Ordered: A Survey of Color Systems from Antiquity to the Present* (Oxford: Oxford University Press, 2008).

Lawson, Ian, "Pigments, Natural History and Primary Qualities: How Orange Became a Color," in *Color: Visualizing Achromatic Knowledge*, ed. Bettina Bock von Wülfingen (Berlin and New York: De Gruyter, 2019), 133–146.

Löwy, Ilana, "The Immunological Construction of the Self," in *Organism and the Origins of Self*, ed. Alfred I. Tauber (Dordrecht et al.: Kluwer, 1991), 43–75.

Lynch, Michael, "Science in the Age of Mechanical Reproduction: Moral and Epistemic Relations between Diagrams and Photograph," *Biology and Philosophy* 6 (1991): 205–226.

Mahony, Martin, and Mike Hulme, "The Colour of Risk: An Exploration of the IPCC's 'Burning Embers' Diagram," *Spontaneous Generations: A Journal for the History and Philosophy of Science* 6 (2012), DOI: https://doi.org/10.4245/sponge.v6i1.16075.

Marx, Vivien, "Beautiful Bioimages for the Eyes of Many Beholders," *Science* 297 (2002): 39–40.

Métraux, Alexandre, "Farbstoffchemie, Farbexperimente und die französische Malerei," in *Farbstrategien*, Bildwelten des Wissens, vol. 4/1, ed. Vera Dünkel (Berlin and Boston: De Gruyter, 2006), 61–68.

Mildvan, Donna (ed.), *AIDS*, Atlas of Infectious Diseases, vol. 1 (Philadelphia: Current Medicine, 1995).

Millet, Jean Kaoru, and Gary Whittaker, "Host Cell Proteases: Critical Determinants of Coronavirus Tropism and Pathogenesis," *Virus Research* 202 (2015): 120–134.

Moser, Jana, and Philipp Meyer, "The Use of Color in Geographic Maps," in *Color: Visualizing Achromatic Knowledge*, ed. Bettina Bock von Wülfingen (Berlin and New York: De Gruyter, 2019), 163–180.

Mößner, Nicola, "Scientific Images as Circulating Ideas: An Application of Ludwik Fleck's Theory of Thought Styles," *Journal for General Philosophy of Science* 47, no. 2 (2016): 307–329.

Nagel, Alexander, "Research on Color Matters: Towards a Modern Archaeology of Ancient Polychromies," in *Color: Visualizing Achromatic Knowledge*, ed. Bettina Bock von Wülfingen (Berlin and New York: De Gruyter, 2019), 51–64.

Nature, "Virology: Coronaviruses," *Nature* 220 (1968): 650.

Nickelsen, Kärin, "The Challenge of Colour: Eighteenth-Century Botanists and the Hand-Colouring of Illustrations," *Annals of Science* 63, vol. 1 (2006): 3–23.

Palsky, Gilles, *Des chiffres et des cartes: Naissance et développement de la cartographie quantitative française au XIXe siècle* (Paris: Comité des travaux historiques et scientifiques, 1996).

Panofsky, Erwin, "Einleitung," in *Studien zur Ikonologie der Renaissance*, ed. Erwin Panofsky (Cologne: Dumont, 1997), 30–61.

Pastoureau, Michel, *Dictionnaire des couleurs de notre temps: symbolique et société* (Paris: Christine Bonneton, 2007).

Pastoureau, Michel, *Red: The History of a Color* (New Jersey: Princeton University Press, 2017).

Pearson, Helen, "Image Manipulation: CSI: Cell Biology," *Nature* 434, no. 7036 (2005): 952–954.

Peirce, Charles Sanders, *Collected Papers of Charles Sanders Peirce*, vol. 4: The Simplest Mathematics, Book 2: Existential Graphs, Chapter 6: Prolegomena to an Apology for Pragmatism, §3: Graphs and Signs, 533–538, ed. Charles Hartshorn and Paul Weiss (Cambridge, MA: Harvard University Press, 1933 [1906]).

Peterson, Daniel A, "Images: Keep a Distinction between Beauty and Truth," *Nature* 435, no. 7044 (2005): 881–881.

Pörksen, Uwe, *Weltmarkt der Bilder: Eine Philosophie der Visiotype* (Stuttgart: Klett-Cotta, 1997).

Pulliam, Heather, "Color," *Studies in Iconography* 33 (2012): 3–14.

Pyle, Cynthia M., "Art as Science: Scientific Illustration, 1490–1670 in Drawing, Woodcut and Copper Plate," *Endeavour* 24, no. 2 (2000): 69–75.

Ramharter, Esther, "Do Signs Make Logic Colored? Tendencies around 1900 and Earlier," in *Color: Visualizing Achromatic Knowledge*, ed. Bettina Bock von Wülfingen (Berlin and New York: De Gruyter, 2019), 65–80.

Rheinberger, Hans-Jörg, *Toward a History of Epistemic Things: Synthesizing Proteins in the Test Tube* (Redwood City, CA: Stanford University Press, 1997).
Rosello, Mireille, "Pictures of a Virus: Ideological Choices and the Representation of HIV," *French Cultural Studies* 9, no. 27 (1998): 337–349.
Rossi, Michael, "Visualizing Viruses," *London Review of Books*, 23 April 2020, online: https://www.lrb.co.uk/blog/2020/april/visualising-viruses (accessed 25 July 2023).
Ruska, Helmut, *Ergebnisse der Hygiene[,] Bakteriologie[,] Immunitätsforschung und Experimentellen Therapie*, vol. 25 (Berlin and Heidelberg: Springer, 1943).
Satheesh, Dhurairaj, Annamalai Rajendran, and Kasi Chithra, "Protein-Ligand Binding Interactions of Imidazolium Salts with SARS CoV-2," *Heliyon* 6, no. 11 (2020): e05544, DOI: https://doi.org/10.1016/j.heliyon.2020.e05544.
Schneider, Birgit, "Red Futures: The Colour Red in Scientific Imagery of Climate Change. Disaster as Image," in *Iconographies and Media Strategies across Europe and Asia*, ed. Monica Juneja and Gerrit Jasper Schenk (Regensburg: Schnell & Steiner, 2014), 183–194.
Schneider, Birgit, "Burning Worlds of Cartography: A Critical Approach to Climate Cosmograms of the Anthropocene," *Geo: Geography and Environment* 3, no. 2 (2016): e00027, DOI: https://doi.org/10.1002/geo2.27.
Schneider, Birgit, and Thomas Nocke, "The Feeling of Red and Blue—A Constructive Critique of Color Mapping in Visual Climate Change Communication," in *Handbook of Climate Change Communication*, vol. 2, ed. Walter Leal Filho, Ilija Djekic, Sergiy Smetana, and Marina Kovaleva (Cham: Springer, 2018), 289–303.
Sofi, Mohd Sharjeel, Aadil Hamid, Sami Ullah Bhat, "Coronavirus COVID-19: A Critical Review of Its History, Pathogenesis, Transmission, Diagnosis and Treatment," *Biosafety and Health* 2, no. 4 (2020): 217–225, DOI: https://doi.org/10.1016/j.bsheal.2020.11.002.
Sonnevend, Julia, "A Virus as an Icon: The 2020 Pandemic in Images," *American Journal of Cultural Sociology* 8, no. 3 (2020): 451–461.
Temkin, Ann, et al. (eds.), *Color Chart: Reinventing Color, 1950 to Today* [= exhibition catalogue] (New York: The Museum of Modern Art, 2008).
Thürlemann, Felix, "Grün—die verstoßene Vierte: Zur Genealogie des modernen Farbpurismus," in *Rot—Gelb—Blau: Die Primärfarben in der Kunst des 20. Jahrhunderts, Kunstmuseum St. Gallen, Friedericianum, Kassel*, ed. Bernhard Bürgi (Stuttgart: Gerd Hatje, 1988), 11–28.
Tufte, Edward, *Envisioning Information*, vol. 2 (Cheshire, CT: Graphics Press, 1990).
Wald, Priscilla, *Contagious* (Durham, NC: Duke University Press, 2008).
Wald, Priscilla, "Contagious: The Outbreak Narrative," *Center for Humanities in an Urban Environment Archives* 11 (2020), online: https://digitalcommons.fiu.edu/chue_archive/11/ (accessed 25 July 2023.
Walsh, Lynda, "Visual Strategies to Integrate Ethos across the 'Is/Ought' Divide in the IPCC's Climate Change 2007: Summary for Policy Makers," *Poroi: Issues in the Rhetoric of Science and Technology* 6, no. 2 (2009): 33–61.
Weingart, Brigitte, "Viren visualisieren: Bildgebung und Popularisierung," in *Virus! Mutationen einer Metapher*, ed. Ruth Mayer and Brigitte Weingart (Bielefeld: transcript Verlag, 2004), 97–130.
Woody, Andrea I., "Putting Quantum Mechanics to Work in Chemistry: The Power of Diagrammatic Representation," *Philosophy of Science* 67 (2000): 612–627.
Yao, Hangping, et al., "Molecular Architecture of the SARS-CoV-2 Virus," *Cell* 183, no. 3 (2020): 730–738.
Zimmer, Carl, "The Coronavirus Unveiled," *The New York Times*, 9 October 2020, online: https://www.nytimes.com/interactive/2020/health/coronavirus-unveiled.html (accessed 25 July 2023).