TEXT 3

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IMAGES OF KNOWLEDGE ARE FIGURES OF THOUGHT

WHY KNOWLEDGE NEEDS DESIGN

"Designers, inasmuch as they are included in scholarly working processes at all, are generally responsible for the packaging, distribution or popularisation of results. This fact is also anchored institutionally in curricula and job profiles, and is even reflected in tender processes and funding criteria, though it is often beholden to hierarchies of those who produce and those who depict."

Kathrin M. Amelung, John A. Nyakatura and Christof Windgätter, "Wissen braucht Gestaltung: Zur Rolle von Wissenschaftsillustrationen in Wissensprozessen," call for papers, Excellence Cluster "Bild Wissen Gestaltung" at Humboldt University of Berlin, October 20–21, 2017, accessed November 14, 2019, https://interdisciplinary-laboratory.hu-berlin.de/de/content/wissen-braucht-gestaltung/ (translated from German).

CREATING IMAGES OF KNOWLEDGE

We live in a knowledge and information society. Our production and consumption of information is increasingly taking place via images and visualisation. Our engagement with the function and meaning of images in our knowledge society leads us to ask questions about the potency of images and thus also questions of responsibility. How do images of knowledge affect our understanding of science and scholarship? How do images arise that determine the societal understanding of knowledge? The question as to how designers might influence this process is casting more and more light on the visualisation of knowledge as a discipline, and on what is required when training designers.

"A picture is worth a thousand words"—this adage expresses the fact that images represent reality differently from language. An image can condense long texts and complex content into an easily comprehensible form. This is especially the case with scientific images, which are generally understood as didactic tools and as aids to learning and teaching. The idea that scientific illustrations exclusively serve the process of information transfer is a widespread misunderstanding.

IMAGES OF KNOWLEDGE ARE FIGURES OF THOUGHT

Images also always represent thought processes. A pictorial depiction allows one to grasp knowledge at the level of the senses and thus makes it negotiable. Images and visualisations are thus core components of model-based research processes and of knowledge production. They are not just used by designers; many researchers also use graphic depictions of their ideas as a highly effective means of reflection and self-interroga-

FIG.1
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FIG.2
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Ronald D. Gerste, "Die Geschichte einer Wasserpumpe in London," *Neue Zürcher Zeitung*, March 21, 2013, accessed November 14, 2019, http://www.nzz.ch/wissen/wissenschaft/die-geschichte-einer-wasserpumpe-in-london-1.18049701.

Harry Robin, *Die wissenschaftliche Illustration: Von der Höhlenmalerei zur Computergraphik* (Basel: Birkhäuser, 1992), 21 (translated from German).

Scientific images reproduce the same content repeatedly, in a very similar manner. See Alexander Vögtli and Beat Ernst, *Wissenschaftliche Bilder: Eine kritische Betrachtung* (Basel: Schwabe, 2007).

Klaus Sachs-Hombach, "Bilder in der Wissenschaft," in *Visualisierung und Erkenntnis—Bildverstehen und Bildverwenden in Natur- und Geisteswissenschaften*, eds. Dimitri Liebsch and Nicola Mößner (Cologne: Herbert von Halem, 2012), 32 (translated from German).

tion. Famous historical examples are the sketches of the tree of life by Charles Darwin (ca. 1837) and the cholera diagram by John Snow.

According to Harry Robin, the drawing is the simplest and oldest form of scientific illustration. "The scientist tells us: 'I looked, and this is what I saw.' Such images arise in a direct interaction between the observer and the object or process he is observing. [...] These images are pure description." But every such description, no matter how "pure," also contains a theory, or at least reveals the current state of knowledge (whether consciously or not), and thereby influences the starting point for later research questions and knowledge formation.

With the increasing distribution of scientific images, both through the mass media and through specialist journals, visualisations have also become established among a broader public as a fixed component of scientific research and scientific proofs. The lasting impact of these "images of thought" can be seen not least in how so-called "canonic images" of abstract facts have become fixed in the collective memory, even though their knowledge base has long moved on (such as the double helix of DNA and the tree of life). This fact requires designers to have a high degree of awareness in dealing with such references, and a constant state of critical reflection on their design decisions in the context of cultural and societal influences.

IMAGES AS EMPIRICAL PROOF

Every scientific research process, whether in molecular biology or in astronomy, is initially based on well-founded observation and on empirical findings. Measuring and documenting are basic aspects of all empirical research. Often, measuring instruments present findings in the form of images. Images that "provide an alternative means of perceiving those areas that are not accessible via the naked eye [...] take on the task of empirical proof." These proofs are provided by increasingly powerful image-giving procedures that produce high-resolution, seemingly objective images. These images are subject to shifting conditions of production, and in their reception—like other forms of image—they are dependent on individual factors, on perception psychology, and on different contexts. They are therefore customisable in most cases, and their design has, in turn, an impact on their epistemic value.

Our knowledge of these image processes is complex, and has only become more so since the further development of imaging techniques. While X-ray images are still bound to physical reality through their exposure process and remain comprehensible to a certain degree, "computed" images and their depiction and materialisation are completely divorced from any physical reality and from the powers of our imagination. The societal acceptance of scientific research is also a matter of trust. The ability to understand and communicate production processes and their circumstances is thus important for the responsibility of the designer in image visualisation. If we succeed in designing the visual result of the image-giving process in a clearly comprehensible manner, then our trust in the images will not just be maintained, but also strengthened.

See Christan Doelker, *Ein Bild ist mehr als ein Bild: Visuelle Kompetenz in der Multimedia-Gesellschaft* (Stuttgart: Klett-Cotta, 1997).

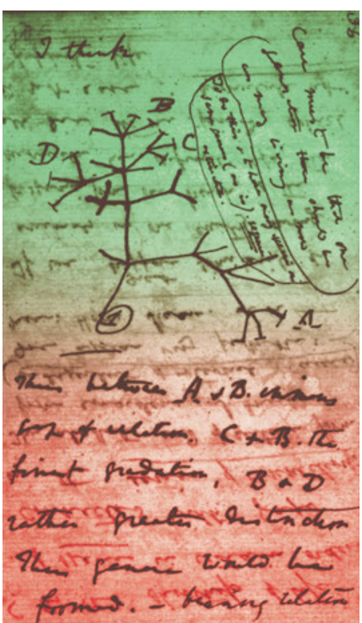
In a review of Lorraine Daston and Peter Galison's book *Objectivity* of 2007, Michael Hampe writes that "almost everyone regards science as an important cultural project [...] because it is committed to values such as truth, certainty and objectivity." Daston and Galison describe making images as a technology that "serves objectivity" because no other such technology "is as old and as omnipresent." This stands in stark contrast to the dwindling trust in science that is in turn linked to the fact that "the more people are active in this field, and the more they are all exposed to the pressure of competition for meagre resources, the more often dubious careerists will emerge who are utterly unconcerned with truth, certainty and objectivity."

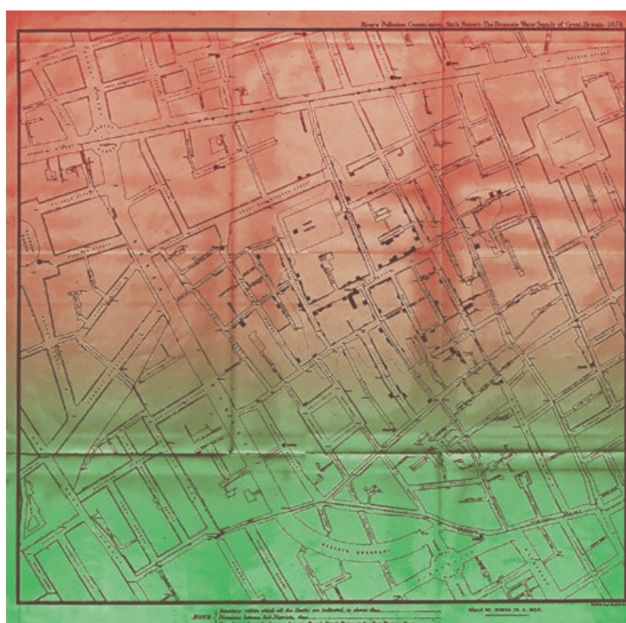
Michael Hampe, "Vom Lilienbild zur Teilchenspur," *Süddeutsche Zeitung,* April 2, 2008, accessed November 14, 2019, http://www.buecher.de/shop/fachbuecher/objektivitaet/daston-lorraine-galison-peter/products_products/detail/prod_id/46775510 (translated from German).

MODELLING AND THE PRIMACY OF LANGUAGE

The questions as to "why?" and "how?" are driving the search for new knowledge. Observation is followed by induction, interpretation and the process of forming a hypothesis. A multitude

FIG.1 Images of knowledge always also represent thinking processes. Probably the first depiction of evolution as a branching tree: A sketch made by Charles Darwin in his “Notebook B.” Cambridge University Library (1837).
FIG.2 The Cholera Diagram by John Snow (1854). Snow marked the deaths from cholera with dots on the map of London and established the existence of a clear cluster of deaths near the water pump in Broad Street.





of individual cases can be made to speak for themselves by means of order, clarity and systematics: occasionally, they also allow for generalities. The data thereby gathered is condensed into models by means of analysis, recognising patterns and causalities. These models not only simplify, but also explain. This step of scientific modelling remains dominated by the conventions of scientific communication, which are still linguistic in nature (different forms of publication, articles, posters). Even before the invention of photography, images were used as empirical proof and in scientific arguments. Images do not just play an important role in scientific diagnosis and documentation, but also in contexts of justification.

With the "iconic turn," many sciences shifted for the long-term towards the image as an object of research, and extolled a kind of "pictorial thinking" as the method of the future. A "visual culture" was postulated that would create scientific rationality by analysing images. According to W.J.T. Mitchell, "the picture now has a status somewhere between [...] a 'paradigm' and an 'anomaly,' emerging as a central topic of discussion in the human sciences in the way that language did: that is, as a kind of model or figure for other things (including figuration itself), and as an unsolved problem [...]."

Sachs-Hombach, "Bilder in der Wissenschaft."

The concept of the "pictorial turn" originated with the American art historian William J. T. Mitchell (see W. J. T. Mitchell, *Picture Theory: Essays on Verbal and Visual Representation* (Chicago, IL: University of Chicago Press, 1995). The phrase "iconic turn" was coined by the art historian Gottfried Boehm, ed., *Was ist ein Bild?* (Munich: Wilhelm Fink Verlag, 1994).

Mitchell, *Picture Theory,* 13.

The omnipresent use of digital image processing, computer graphics and information visualisations in the natural sciences is increasingly a matter of reflection in philosophy and image theory. The influence of this process of reflection on scientific practice remains minimal, however, because the discourse remains largely limited to image theory. Design knowledge and design methodologies barely have an impact on scientific practice. Here, further sensitisation and clarification are necessary in order to convince scientists of the added value that their work can receive through design knowledge and design methods.

DIALOGUE THROUGH AND WITH IMAGES

When designers and scientists work together on an equal footing, they bridge a gap by being able to utilise images equally as a medium of research and as a means of conveying language. Our experience has shown that research processes, their communication, and thus also people's trust in science, can be altered permanently if design skills and visual knowledge are already employed at the imaging and measurement stage. Visual knowledge and creativity are also crucial to analysis and modelling. The ability to enter into a dialogue and to work with scientists in this manner is a fundamental component of professional training in this discipline—which makes it different from the traditional job profile. Sustainable collaborations between design and very different scientific institutions provide a basis for making lasting images and models, and making transparent cognitive processes possible. An intensive dialogic analysis refines content and clarifies issues of visual translation through the forms, media and communication concept chosen. This mutual learning process is productive and can generate new research questions for both disciplines.

FINDINGS, INTERPRETATIONS AND VISUAL ARGUMENTS

Using imaging in forensics as an example, we can observe that the form of presenting anatomic injuries of victims of violence makes a decisive contribution to how findings are perceived and interpreted. The high-resolution depiction of the peculiarities and extent of an injury in a victim of violence can ultimately also have legal consequences.

Non-invasive imaging methods of so-called "virtopsy" ('virtual' and 'autopsy'), such as post-mortem computer tomographic 3D reconstructions (PMCT), can document fractures of the bones and skull, and confirm the findings of forensic scientists. Computer tomographs are processed visually so that they convey the impression of a "real" anatomic depiction. While no manipulation of the CT data is itself allowed, the forensic scientists can alter the computational processes (the algorithms) and thereby have a major impact on the resultant form of depiction.

The use of colours and the design of transparencies play a central role here. Colours do not just influence the expressivity and the information density of a visualisation, but also how we interpret the forensic findings. Colours can be "tools of knowledge" that enable us to make information visible that is relevant but has hitherto been hidden, and thus let us interpret it. Interventions in the visualisation software enable us to have a comprehensive influence on the visual implementation of technical CT data in the form of computed visualisations. This also brings risks with it, as in the use of design elements that have a negative impact on the readability of findings—such as a seemingly realistic gloss finish.

In a collaboration with the Institute of Forensic Medicine at the University of Zurich, we were able to demonstrate how design interventions in the visualisation software can communicate medical findings more transparently, more comprehensibly, and with greater scientific precision. For example, the elaborate application of pseudo-colours was able to make exceptionally thin hairline skull fractures visible.

Eloisa Aldomar, "Farbe und Erkenntnis in der virtuellen Autopsie (Virtopsy): Designstrategien zur Visualisierung von Haarriss-Schädelfrakturen in postmortalen computertopografischen 3D-Rekonstruktionen" (Master thesis, Zurich University of the Arts, 2019). A collaborative project between the subject area Knowledge Visualization, ZHdK, and the Institute of Forensic Medicine (IRM), University of Zurich.

FIG.3 P.360

Individual visualisation strategies and their significance were constantly being discussed with the cooperation partner. This discourse improved our understanding of the visual, design aspects that allow forensic scientists to already incorporate visual perception criteria during visualisations of CT data. This in turn makes it possible to reconstruct more comprehensible images. This cooperation resulted in a series of set parameters for design software for different case studies.

Palaeontology is another scientific discipline that is utilising virtual models and 3D visualisation experiments to clarify research questions. Designers were significantly involved in the interdisciplinary research project "Orobates" at the Humboldt University of Berlin, where the terrestrial vertebrate *Orobates pabsti* was reconstructed virtually from fossils and animated both in the form of interactive, digital 3D models and as a robot. The aim was to acquire new knowledge about the anatomy and

The research project "Orobates" by an interdisciplinary team with experts from Humboldt University of Berlin (first author Prof. Dr John A. Nyakatura) and the Ecole polytechnique fédérale de Lausanne, EPFL, with the participation of a designer from the subject area Knowledge Visualization, ZHdK, was described in John A. Nyakatura et al., "Reverse-Engineering the Locomotion of a Stem Amniote," *Nature* 565 (2019): 351–355.

FIG.4 P.361

the behaviour of this long-extinct species, and how it moved.

Nyakatura and Demuth describe the relevance of this interdisciplinary research project and the significance of collaborations between designers and scientists as follows: “The functional analysis of the locomotor system (of recent and fossilised vertebrates) by means of image-processing, computer models and simulations that enable us to carry out virtual experiments allows us to gain insights into the manner in which living environments are utilised [...] and how different organisms interact with each other [...].” With regard to the importance of collaborations between designers and scientists, Nyakatura (a morphologist) and Demuth (a designer) say the following: “Virtual experiments are thus also an important tool for making morpho-functional hypotheses and theories. [...] it is here that we find analytical potential for the simulation that makes an exchange necessary [between designers and morphologists], and presents us with the result right before our eyes. The concretisation thus takes place in an iterative process in which the designer and the morphologist work closely together.”

Another field in which the discourse between the sciences and design can result in productive visualisations is the reconstruction of archaeological buildings. “The visual reconstructions of buildings in which a reconstructed view is linked with a graphic depiction of the archaeological findings offer an interesting variant for understanding visualisations as something argumentative. By offering different ways of depicting the elements that are assumed and deduced, such depictions can be seen as illustrating the connections between different assertions.”

A reconstruction never constitutes a mere depiction, because what we do not know and what we only half-know are also immanent components of every reconstructed depiction of architecture. This is always a process of approximating to reality. Since a reconstruction can only ever be based on incomplete knowledge, the designer influences the content and the impact of a depic-

John A. Nyakatura and Oliver E. Demuth, “Virtuelle Experimente zur Funktionellen Morphologie der Wirbeltiere,” in *Experimentieren: Vergleich experimenteller Kulturen in Wissenschaft und Gestaltung,* eds. Séverine Marguin, Henrike Rabe, Wolfgang Schäffner, and Friedrich Schmidgall (Bielefeld: transcript, 2019), 163 (translated from German).

Nyakatura and Demuth, “Virtuelle Experimente,” 169–171 (translated from German).

Sachs-Hombach, “Bilder in der Wissenschaft,” 34 (translated from German).

FIG.3 The visualisation of computer tomographic data in the form of post-mortum 3D reconstructions makes skull fractures of victims of violence visible. However, particularly thin cracks in skull bones, so-called "hairline skull fractures," are often either inadequately shown or not shown at all when normal manufacturer specifications are used, as they exhibit measured values with particularly subtle thickness differences. The use of false colours and the deliberate increasing of contrast make it possible to show the hairline skull fractures better and more effectively. Excerpt from the master thesis of Eloisa Aldomar (2019). "Colour and Findings in the Virtual Autopsy (Virtopsy)," a joint collaborative project of the specialist department Knowledge Visualization ZHdK and the Institute of Forensic Medicine at the University of Zurich. For the image in original colours see "Farbe und Erkenntnis in der virtuellen Autopsie," http://kvis.zhdk.ch/projekte/farbe-und-erkenntnis-in-der-virtuellen-autopsie.

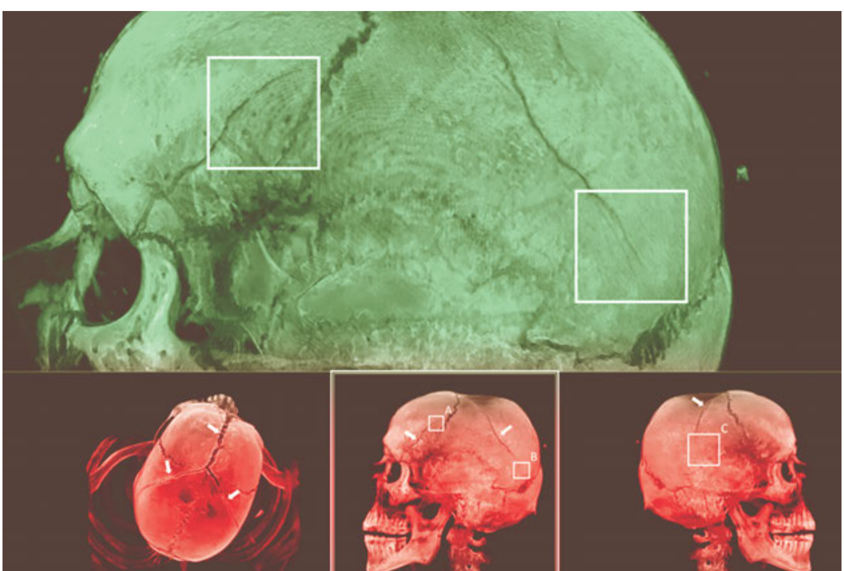
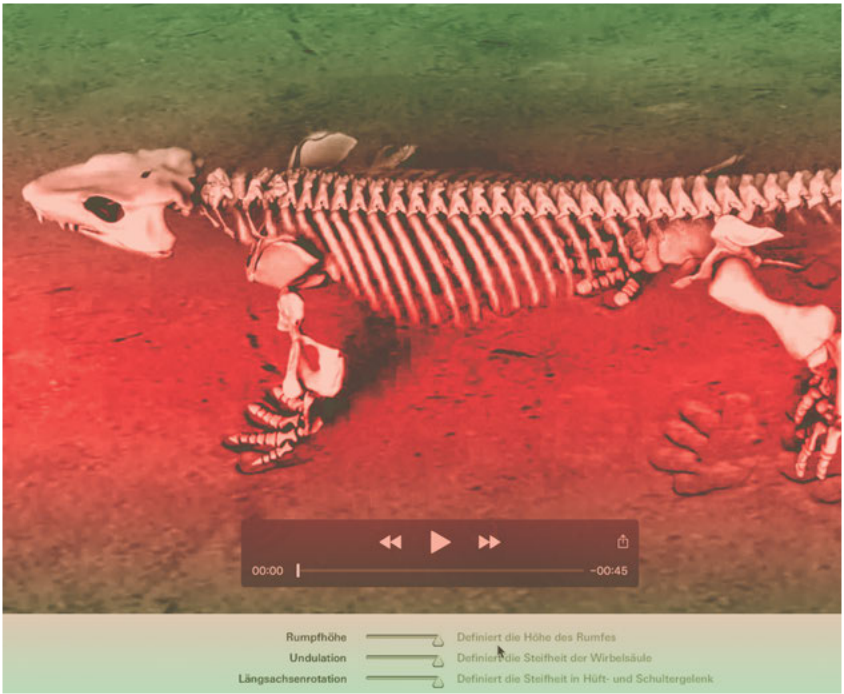


FIG.4 Imaging procedures, 3D computer modelling and "Robotic Palaeontology" make the virtual reconstruction of the fossil land vertebrate *Orobates pabsti* possible. In an interdisciplinary research project, a team of design and scientific experts carried out the reconstruction and functional analysis of the musculoskeletal system and the simulations of *Orobates pabsti's* method of locomotion. This groundbreaking joint project of Humboldt University of Berlin and the EPFL Lausanne, with the support of Knowledge Visualization ZHdK was published in Nature in 2019 (principal author John A. Nyakatura).



tion and takes responsibility for it. So regardless of whether one is dealing with knowledge based on facts or on knowledge based on hypotheses or speculative fabrication, it all has to be handled in a conscious, discriminating manner.

The reconstructed depiction is faced with the challenge of depicting knowledge in a believable, plausible manner. So what exactly is "scientific" about a scientific reconstruction? Scientific procedures mean having comprehensible documentation, the reproducible acquisition and analysis of data, and a plausible hypothesis. The hypothesis and the interpretation of the sources necessary to prove it are part and parcel of scientific methodologies and are of considerable significance, especially for reconstruction processes. But they are only truly "scientific" when it is demonstrated transparently and comprehensibly what is being interpreted, how and why. The scientific visualisation of the reconstruction should also be measured against this aspiration. It would be desirable to have forms of depiction that comprehensibly illustrate the path from the excavation to the findings, their interpretation and a comparison with different theories and their probabilities. Communicating different things requires different communication strategies. For example, gaps in knowledge can be concealed, or the state of knowledge can be presented transparently and recognisably in its incompleteness.

FIG.5 P.363

FIG.6 P.363

Communication strategies that allow for the ingenious merging of scientific findings (archaeological findings or facts) and hypothetical elements (reconstructions, fiction) that can also be differentiated according to their degree of probability, also allow for the verification of the plausibility of each reconstruction. This in turn contributes to identifying new problems and to generating new hypotheses.

Niklaus Heeb and Jonas Christen, "Strategien zur Vermittlung von Fakt, Hypothese und Fiktion in der digitalen Architektur-Rekonstruktion," in *Der Modelle Tugend 2.0: Digitale 3D-Rekonstruktion als virtueller Raum der architekturhistorischen Forschung,* eds. Piotr Kuroczyński et al. (Heidelberg: arthistoricum.net, 2019), 229.

VISUAL KNOWLEDGE FOSTERS THE GENERATION OF KNOWLEDGE

These examples demonstrate that visualisation in many cases is what makes possible the recognition of a finding, and the communication of a discovery. Professional design makes the rec-

FIG.5 The lower portion of a residential tower in Edisried, which dates from the 13th century, is shown semi-transparently in order to offer a view of the verified structure of the ground plan and of today's building. Commissioned piece by Joe Rohrer (2007).

FIG.6 Strategies for conveying fact, hypothesis and fiction in the work of archaeological reconstruction: The abstract archaeological find drawing is perspectively integrated into the illusionist visualisation of the reconstruction of a pit house (Rheinau, dating from 700–825) as an additional information level. The classroom project Bachelor Scientific Visualization by Maurus Zehnder (2016).

ognition process visible and comprehensible; it enables theories and models to be translated into a visual form that allows knowledge to be processed and made negotiable. The quality of the design thus also determines the quality of the discourse.

Their utilisation in recognition processes means that images don't just assume a representative, didactical function, but also, in a narrower sense, a scientific i.e. epistemic function and play a fundamental role in the generation of knowledge and the justification of claims to knowledge.

Sachs-Hombach, "Bilder in der Wissenschaft," 31.

When they are utilised intelligently, visual competence and an appropriate design of the recognition process itself make possible the generation of new knowledge and allow knowledge relationships to be revealed that were hitherto unknown because they could not be seen. The path to success requires setting up interdisciplinary teams for an equitable collaboration between design and science. When such a dialogue of equal partners is successful, the result is added value for scientific research. When visualisation processes translate scientific data and findings into visual models and simulations that are perceptible by the senses, assumptions and hypotheses likewise gain in transparency. To support and further develop this crucial role of visualisation in the production of knowledge will be an important task in our discipline in the future.

KNOWLEDGE NEEDS DESIGN

Scientific images, visualisations and illustrations make a fundamental contribution to a broader, better understanding of knowledge and scientific findings. Images educate. And education is one of the most important tasks in a society. Images are also an integral component of the scientific discourse, which itself is of central importance to socio-political developments. The climate crisis is one example that can demonstrate how strengthening trust in scientific processes by means of transparent, credible communication is more important that ever. As the climate researcher and glaciologist Martin Hoelzle says: "Without realistic visualisations of the future high-mountain landscapes, it is very difficult today to sensitise the broader public to the current problems of climate change in an appropriate manner, and to urge people to confront the coming societal transformations in a positive spirit. Visualisations that are of high technological, artistic and aesthetic quality are a central component of today's science communication regarding climate change and its impact."

Martin Hoelzle, statement made in the context of the collaborative research project "Expedition 2 Grad," http://www.expedition2grad.ch (translated from German).

It is the well-informed, sophisticated expertise of scientific illustrators that actually makes the knowledge contained in images and visualisations relevant in the real world. They make possible a reflective discourse of knowledge, and they provide an impactful means of communicating scientific insights. For these reasons, design is indispensable for understanding knowledge and scientific findings.

EDUCATION IS ONE OF THE MOST IMPORTANT SOCIETAL TASKS