UNIVERSITÄT BAYREUTH

SPEKTRUM

The Science Magazine of the University of Bayreuth ■ Volume 17 ■ Issue 1 ■ October 2021

FOCUS
Uncertainty

Dear Readers,

Prof. Dr. Stefan Leible, President of the University of Bayreuth.

In recent issues of SPEKTRUM, we have been presenting some of the research competencies of the University of Bayreuth in important fields for the future: batteries, hydrogen, food and nutrition, health and biomedicine. In these and many other areas, the interdisciplinary research on our campus has set itself the goal of creatively and responsibly helping to shape new developments in science, business, and society.

At the same time, uncertainty is present everywhere. Indeed, it can create uncertainty and apprehension, but even more so it serves as inspiration and stimulus for innovative ideas and research projects. The current issue of SPEKTRUM uses selected examples to show us how different disciplines deal with the causes and consequences of uncertainty, insecurity, and the probability of error. For example, a European initiative in the natural sciences aims to overcome the pressing problem that published research results can often simply not be reproduced; energy research is working on forward-looking concepts for safe and at the same time climate-friendly power supply; while in legal studies, the question of whether and how legislation should react to new technological possibilities is being discussed with equal vigour.

It is becoming increasingly clear that science is only capable of success and being of long-term benefit to society if it confronts the topic of "uncertainty" critically and self-confidently. Only in this way will it be able to gain and consolidate public trust, which is indispensable for a knowledge-based, highly-developed, technological society. The University of Bayreuth will therefore continue to work together with its partners at home and abroad to promote open communication on scientific challenges, on the content and goals of its own research projects, and the possible consequences of the knowledge gained in the process.

Yours faithfully,

Prof. Dr. Stefan Leible
President of the University of Bayreuth

Further SPEKTRUM issues

On the homepage of the University of Bayreuth you will find previous issues of SPEKTRUM on the following topics:

2/2020: Life Sciences
1/2020: Hydrogen
2/2019: Africa
1/2019: Batteries
2/2018: War
1/2018: Planet Earth
2/2017: Sustainability
1/2017: Governance
2/2016: Molecular Bioscience

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This issue of our science magazine SPEKTRUM is what at first glance appears to be an unusual focus. While our focus is usually on advances in knowledge, innovations, and ground-breaking research projects, this time it will be on "uncertainty". The topic has come to the fore because the Covid 19 pandemic and its consequences have caused uncertainty and mistrust in large parts of the public. In addition, it has become clear that research institutions are increasingly perceived by those responsible in government, business, and society as representing partners in the development of viable concepts for the future and they are being increasingly called upon to act as such.

The following contributions use examples from very different disciplines to show that science and research have to deal with uncertainty on an almost daily basis. Tried and tested methods are reaching their limits, unresolved questions are hindering the progress of knowledge, and social expectations of a supposedly comprehensive problem-solving competency are proving unrealisable. The demand occasionally heard in the months of the pandemic that government should "follow the science" reinforces the false notion that science is a uniformly structured system and possesses definitive findings that are suitable to relieve decision-makers of the weight of their responsibility. In fact, however, science is at its core an open, multi-voiced process that is substantially driven by uncertainty, doubt, controversy, and error.

Consequently, this issue of SPEKTRUM also contains examples of how science is not limited to trying to overcome uncertainty with the methods and tools at its disposal. Equally important seems to be its potential to develop rationally justified, ethically responsible, and at the same time practicable procedures for dealing with – possibly irreversible – uncertainty. There is much to suggest that science is indispensable for a prosperous future in this respect as well.

With best regards,

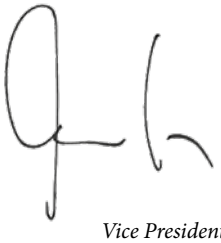

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Figure left: The sculpture "you are free" by Robert Kessler on the campus of the University of Bayreuth (Photo: Christian Wißler).

Aerial view backpage: The Campus of the University of Bayreuth (Photo: © Christian Bay).

Uncertainty

Biominerals provide important impetus for the design of innovative functional materials (Photo: ist).

Today, the "reproducibility crisis" affects a wide variety of disciplines in the natural sciences (Photo: ist).

Towards the modern age

European knowledge about the world that emerged in the early modern period derives to a large extent from non-European sources (Photo: ist).

Nature & Technology

Knowledge & Decision

A new study has examined reasons for different behavioral adaptations in the pandemic (Photo: ist).

Scientific research always has access to only a very limited section of the universe, cf. pp. 26-29 (Photo: ist).

Reliable simulations are essential for products to meet high safety standards (Photo: ist).

Society & Economy

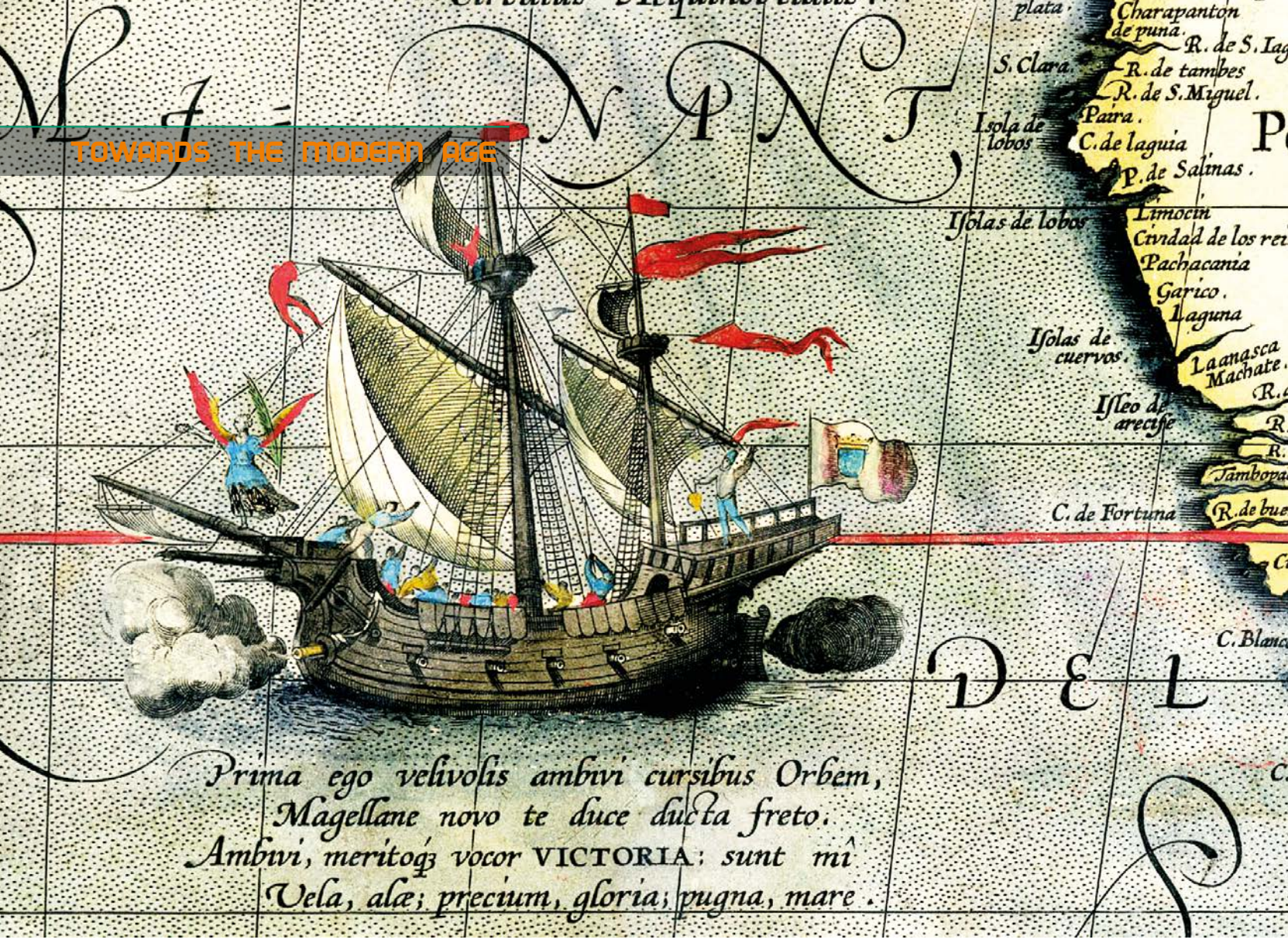
Society & Law

Understood as uncertainty about what has happened, epistemic uncertainty shapes legal practice (Photo: ist).

Flexibilization is the key to sustainable energy systems of the future (Photo: ist).

Global agricultural supply and investment chains can create insecurity in the Global South (Photo: ist).

Governing in the pandemic



Susanne Lachenicht

New uncertainties

The Age of "Discovery"

Ferdinand Magellan's ship "Victoria", detail from a world map by Abraham Ortelius (1527-1598) (Source: wikimedia commons / www.helmink.com / CC-PD-Mark).

In 1986, the year of the Chernobyl nuclear disaster, a book by a German sociologist caused a sensation: "Risk Society. On the Way to a Different Modernity" by Ulrich Beck (1944-2015). Here, the author announced a break in modernity as a result of changes in industrial society, which was fundamentally changing in the face of new risks. This second, reflexive modernity produces a "logic of risk production", technical-economic development resulting in risks such as environmental and climate problems, but also societal problems. However, what is perceived as a risk is always the result of social construction processes.

Critics have countered that risk production and strategies for dealing with it have existed in all societies, triggered by natural disasters, imperial expansion, or new technologies. In fact, all societies have had to deal with risks and the resulting uncertainties, albeit to different degrees and not always with global reach.

An epoch of great uncertainty, among others, was the period from around 1400 onwards, which we refer to from a European perspective as the Renaissance, the Reformation, and the Age of "Discovery". Not least because of the crusades, contacts of Christian Europeans with Muslim and Christian Arabs, with Jews, Greeks, Persians, Byzantines, with Mamelukes, Saracens and Ottomans in Eastern Europe had intensified. On the Iberian Peninsula, the crusade idea led to the Reconquista, the Christian reconquest of the Iberian Peninsula from Moorish hands. Connected with this was the Conquista, i.e. the conquest of parts of North Africa, the Canaries, Azores, Madeira. New and old worlds of knowledge, the so-called rediscovery of antiquity, as well as the confrontation with the worlds of knowledge of other societies, with new technologies – all this fundamentally challenged seemingly fixed models of world explanation in western Christianity.

The explanation of the world with the help of texts from Greek and Roman antiquity, with the help of the Bible, and here above all the Old Testament, was shaken by the "discovery" of the Americas. That there should be another world, a separate continent, another hemisphere beyond the Pillars of Heracles, as the Strait of Gibraltar was called at the time, that there should be another world beyond God's one world, consisting of Europe, Asia and Africa, seemed inconceivable. Since the western extent of the Americas was not known for a long time, the consideration was also repeatedly put forward that perhaps it was only islands belonging to the Chinese empire. But the exploration of the coastline from Labrador to Tierra del Fuego, and finally, Ferdinand Magellan's circumnavigation of the globe in 1520/21, brought certainty. Here lay a huge, unknown continent that the ancients seemed not to have known about in their writings. Historians like Anthony Grafton, who teaches at Princeton University, or Anthony Pagden, who works at UCLA, have called this experience a "shock of discovery". From the European point of view, the world had to be reordered. In addition to the old uncertainties, new ones of unprecedented dimensions were added.

Unknown worlds – risks and speculation

On the way to unknown new worlds, there was uncertainty about the winds and currents that might take the Europeans on their sailing ships to distant places but would prevent them from returning home; new climates, landscapes, and cultures brought new risks. Sources from the Age of Discovery document that the princes of Europe were well aware of the risks sailors took in their mission to explore a sea route to the west and conquer new lands. The conquistadores, freebooters, conquerors were rewarded by patents issued to them by their princes for lands over whose resources they had no power of disposal at all. In 1492, Christopher Columbus was granted by Isabella of Castile the rights of admiral, viceroy, and governor over all the regions he would visit on his voyage and which - in the opinion of many scholars of the time - should actually have been in the dominions of the Great Khan of China. Like Columbus, the Venetian Giovanni Caboto was commissioned in 1496, in this case by King Henry VII of England, to take possession of new lands. Caboto's willingness to take unimagin-

Fig. 1: Two rocky cliffs mark the Strait of Gibraltar: the Rock of Gibraltar in the south of the Iberian Peninsula (left foreground) and Mount Jebel Musa on the North African side. They have been called the "Pillars of Hercules" since ancient times. According to Greek tradition, Heracles installed the inscription "No more further" (Latin: "Non plus ultra") here, as a visible sign of the end of the world. Under the Emperor Charles V, who also reigned as king over Las Hispanas, two columns with the opposite motto "Plus Ultra" were incorporated into the Spanish coat of arms, marking a claim to rule that spanned the globe (Photo: wikimedia commons / Hansvandervliet / PD-self; coat of arms: wikimedia commons).

Fig. 2: John Cabot in traditional Venetian garb by Giustino Menescardi (1762). A mural painting in the 'Sala dello Scudo' in the Palazzo Ducale (Source: wikimedia commons / CC-PD-Mark).

Fig. 3: Vespucci discovers America. Engraving by Theodor Galle (1571-1633) after an allegory by Johannes Stradanus (Jan van der Straet, 1523-1605) (Source: wikimedia commons / CC-PD-Mark).

1 Richard Hakluyt: Prinicipale Navigations. London 1509.

"From the European point of view, the world had to be reordered. In addition to the old uncertainties, new ones of unprecedented dimensions were added."

able risks, challenge Fortuna, and place himself in God's hands was rewarded as follows: Caboto was given the right "[to] subdue, occupy and possess all such townes, cities, castles, and isles of them found, which they can subdue, occupy, and possess", and "be holden and bounder of all the fruits, profits, gains, and commodities growing of such navigation." [1] In the age of discovery, uncertainty and risk-taking were thus associated in many of these patents with the right to exploit land, resources, and people in the worlds that were new to Europeans, regardless of the rights of the people already living there.

Fig. 4: Cyrano takes off with the help of round bottles filled with dewdrops and heated by the sun to float to the moon. Instead of the moon, however, he lands in Quebec, in New France. Illustration from the second volume of the complete edition of the works of Savinien de Cyrano de Bergerac (1619-1655) printed in Amsterdam in 1708 (Source: wikimedia commons / CC-PD-Mark).

Facing uncertainty

In historical, cultural, and literary studies, the term "affirmative speculation" is used in the context of risk research or in the analysis of "Cultures of Speculation":

"Affirmative speculation is founded on a paradox: it functions and thrives by concerning itself with an uncertainty that must not be reduced to manageable certainties. By definition, affirmative speculation lives by thinking in the vicinity of the unthinkable (...) As a mode of radical experimentation with the future, it experiments with those futures that are already here and now and yet are different from the here and now. Paradoxically, in affirmative speculation – and hence at a moment of potent self-affirmation – what we affirm is something that has the potential to undo us: this is not, in other words, a self-congratulatory affirmation of what we are; it is, rather, an affirmation of what we might become."

Uncertain Commons: Speculate This!, Durham 2013, 72.

As an analytical term, it is useful for a variety of literary works of the early modern period that oscillate between certainties and uncertainties, past, present, non-time and future, reality and imagination, seriousness and satire, old European world and non-European worlds, or hold up a (distorting) mirror to their present and make new worlds imaginable:

- Amerigo Vespucci: Mundus novus (1504)
- Thomas Morus: Utopia (1516)
- Tommaso Campanella: La città del sole (1623)
- Francis Bacon: The New Atlantis (1627)
- Cyrano de Bergerac: Les États et Empires de la Lune (posthum 1657) und Les États et Empires du Soleil (posthum 1662)
- Jonathan Swift: Gulliver's travels (1726)

Europeans countered the risks of the voyages of discovery, the attempts at conquest and colonisation, many of which failed, in many ways. The financiers improved the insurance systems already widespread in the Mediterranean and used, among other things, the calculus of probability, for which Blaise Pascal (1623-1662) and Pierre de Fermat (1607-1665) laid important foundations in the 17th century, to calculate financial risks. Risks posed by storms, piracy, shipwrecks, mutinies, attacks by other imperial European powers or indigenous populations were primarily intended to hedge the financiers in Europe itself. The aim here was to bring risk under control, to replace uncertainty with calculable risks.

At the same time, the confrontation of Europeans with worlds that were new to them produced what the research group "Cultures of Speculation" at the University of Bayreuth and the University of California at Davis calls "affirmative speculation": philosophical and theological writings as well as literary productions in the form of fictional and real travelogues, parodies, satires, and fantastic tales. These works told of real and surreal risks and uncertainties, or held up a mirror (speculum) to the societies of their time. At the same time, they designed – sometimes seriously, sometimes decidedly unseriously – potentially new worlds. It was about more than bringing risks under control, making them calculable. The uncertainties of the new brought forth even more new, even more possible, potential, but also speculation about impossible or undesirable worlds. In many of these satirical writings, the fictional events narrated in them were relegated by their authors to an "un-place" (utopia) where they played out outside the real course of history in a "non-time". They were often named as undesirable projections of society. But for a later reading public, the content of these writings became a vision with a promising future. Ideas of common property inspired early socialists in the late 18th and early 19th centuries to new social experiments as well as revolutionary demands and movements, especially at the time of the French Revolution or the European revolutions of 1830 and 1848. The same applies to some literary satires of the Renaissance and Baroque periods. In their own time, they were "revolutionary" if they imagined, for example, democratic rights for all or equality between men and women. It was only in la-

ter eras that ideas from these literatures were taken up and, after long struggles, turned into reality.

Non-European sources of the "New Sciences"

But Europeans also met the uncertainties of new worlds with what is called the New Sciences. These were attempts to better understand God's world in its order and thus the laws of nature - not least in order to better subdue the earth in the spirit of the Old Testament. In 1620, Francis Bacon wrote in his "Instauratio magna" about the New Sciences: "[it] could affect the course of nature in useful ways, knowledge about how to ward off disease, improve crops, extend the span of life, and enhance the general welfare".[2]

In mapping, improved knowledge of climate, environment, geology and geography, botany, zoology, societies and their cultural practices, Europeans in all regions of the world depended above all on the knowledge of those whom they subjugated by force in the long term through colonisation or with whom they traded. In recent years, the history of knowledge and the history of science have empirically demonstrated this connection in many ways. European knowledge about the world, as found in academies and universities, encyclopaedias, travel reports and descriptions of nature, scholarly journals, museums, libraries and archives, can be traced back to a large extent to knowledge worlds and knowledge systems of non-European and non-Christian knowledge carriers. What these knowledge bearers knew about their own worlds, which were often forcibly subjugated by the Europeans, they communicated - often under duress – to these same colonisers, so that they became "go-betweens" between the worlds of knowledge. The knowledge they transmitted was declared European knowledge in the context of colonisation and the Enlightenment. Together with the empirical experience of Europeans, it corrected the knowledge they believed they had about the world. It turned out, for example, that Pliny the Elder in his Naturalis historia (c. 77 AD), which was long recognised as valid, was only partially correct in his description of the world and its flora and fauna. Not only did Europeans not meet the monsters, mermaids, cephalopods, and other creatures described by Pliny at the edges of the world, but there were quite different, never expected strange creatures like anteaters, sloths, and kiwis. In the often verbalised names for regions, landscapes, rivers, natural phenomena, plants, and animals, there are still traces of the knowledge that the "go-betweens" brought to European knowledge. In pharmacy and medicine, in new methods of agriculture and ecology, the knowledge they gained in non-European contexts is still present today.

However, the New Sciences increasingly challenged that from which they themselves had emerged: Judeo-Christian-Muslim notions of the beginning and end of the world as God had created it. They shook the relative certainty that religious explanations of the world had brought with them, despite all the doubt; they created new uncertainties and at the same time a new search for more certainty about the origin and course of the world.

Fig. 5 (left): Courtyard of the Amsterdam Stock Exchange, painting by Emanuel de Witte (1617-1692) from 1653 from the Museum Boijmans Van Beuningen, Amsterdam (Source: wikimedia commons / CC-PD-Mark).

RECOMMENDED READING

S. Lachenicht: Histoires naturelles, récits de voyage et géopolitique religieuse dans l'Atlantique français; XVIe et XVIIe siècles. Revue d'Histoire de l'Amérique française (2016) 69/4, 27-45 (Montreal). Awarded with the prize Guy et Liliane Frégault (Montreal).

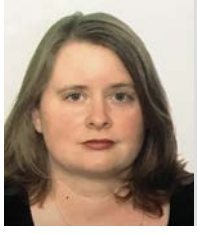
S. Lachenicht: How the Americas Came to Be Known as 'the Americas'. A Historical Approach to the Western Hemisphere, in: V. Depkat, B. Waldschmidt-Nelson (eds.): Cultural Mobility and Knowledge Formation in the Americas. Heidelberg 2019, 13-29.

S. Lachenicht: Cultures of Speculation, Histories of Speculation, in: J. Cortiel et al. (eds.): Practices of Speculation. Modeling, Embodiment, Figuration. Bielefeld 2020, 31-48.

2 Anthony Grafton et al. (eds.): New Worlds, Ancient Texts. The Power of Tradition and the Shock of Discovery. Cambridge/MA und London 1992, 197.

Fig. 6: Francis Bacon, Lord Chancellor of England. Portrait by Frans Pourbus the Younger (1569-1622) from 1612 (Source: wikimedia commons / CC-PD-Mark).

AUTHOR



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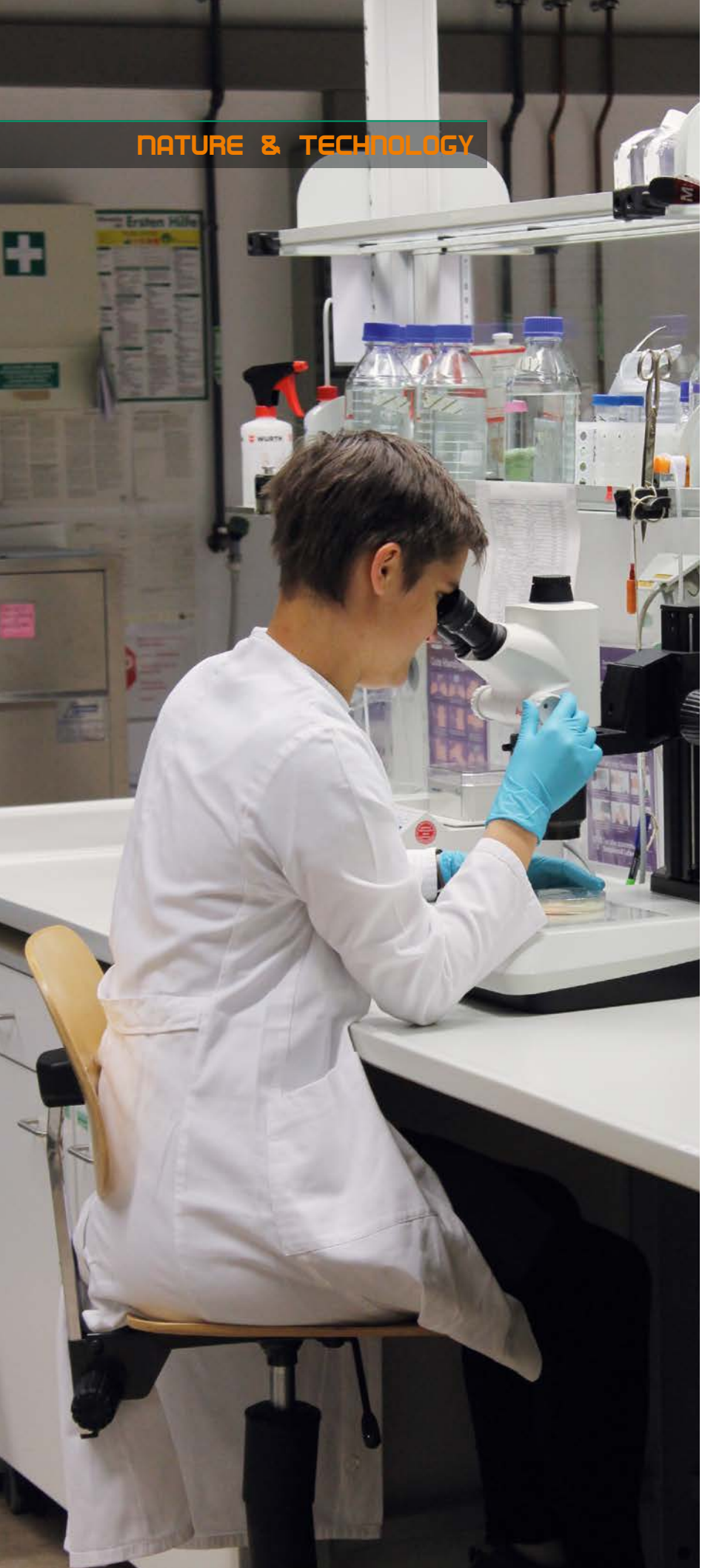

Matthias Weiss

Creative uncertainty

On the physics of self-organisation in living matter

Rebecca Benelli M.Sc., doctoral student in the Weiss lab, examines the viability of embryos of the nematode Caenorhabditis elegans (Photo: Christian Wißler).

The term "uncertainty" often has a negative connotation in everyday life, for example in situations that are perceived as potential threats to the status quo. In science, on the other hand, uncertainty is indispensable in arousing curiosity and spurring researchers on the exploration of uncharted territory. Science reduces uncertainty by creating knowledge and it therefore expands the boundaries of human certainty, but in doing so it also raises new and unforeseen questions. Already developed tools and established knowledge guide the advance into the unknown, but at the same time, they are questioned and possibly abandoned themselves. Supposedly the most famous steps into the unknown that was accompanied by a formidable collapse of current wisdom, is associated with the names of Max Planck and Albert Einstein.

Uncertainty is not only a constant companion and driver of scientific progress in the general sense, it is also constantly present in everyday laboratory life. Every measurement signal shows a certain variation, for which the term "fluctuations" has been coined. Whether and to which extent quantitative measurements can create certainty, i.e. whether fluctuations tend to enhance uncertainties or actually lead to deeper insights, depends on their causes. In many cases, fluctuations are simply due to technical limitations of the measurement equipment. Of particular scientific interest, however, are fluctuations caused by the fact that an object of interest (the sample) is intrinsically dynamic. Fluctuations caused by this cannot be eliminated, even with a perfect measurement technology, but they rather tell a story about the secret life of the sample. Allowing for deep insights into the development of the particular system under investigation, fluctuations are of utmost importance in virtually all areas of physics.

Fluctuations in living organisms

Biophysics often focuses on fluctuations associated with transport and self-organisation processes in living organisms. These processes occur on many different length and time scales, and they are necessary to maintain vital functions in living cells, e.g. as indispensable cues for embryonic development. While an "average behaviour" may often be determined the precise details of developmental steps of an individual remain, at least in part, uncertain due to fluctuations. For example, humans will always be broadly similar in terms of their external appearance, but details such as individual eye colour – up to and including differently coloured eyes, as occasionally observed for individuals – are subject to significant fluctuations.

Moreover, living organisms are far from thermal equilibrium as food uptake continuously supplies external energy that may be converted to kinetic energy or information processing. Notably, the amount of the molecular energy storage (adenosine triphosphate, ATP) that is being turned over in the body of an adult human over a single day, corresponds approximately to his or her own body weight. Thus, each human cell, turns over about ten million ATP molecules every second! Since every splitting of an ATP molecule is almost instantly compensated by the formation of a new ATP molecule (using the ingested nutrients), the mass of the body remains practically unchanged. Fluctuations caused by ATP-driven, active processes are not only a signature of living systems but they may even be constitutive for life in general.

Mechanics can reduce uncertainty during embryogenesis

Following up on these general remarks, the next paragraphs are devoted to a small overview of self-organiziation phenomena in the course of embryonic development that are studied in the Department of Experimental Physics I at the University of Bayreuth. As a model system, an established and widespread model organism is used – the approximately one millimetre long and transparent nematode *Caenorhabditis elegans*. The genome of *C. elegans* has long been decoded and today a plethora of genetically modified strains of this worm are available that can be studied with modern fluorescence microscopy methods, such as light-sheet microscopy. Interestingly, all adult animals of *C. elegans* have exactly 959 somatic cells and more than 99 percent are herma-

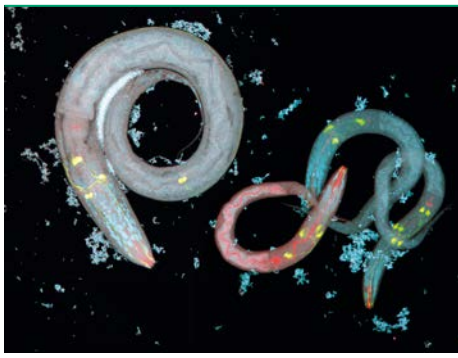

Fig. 1: Threadworms of the species Caenorhabditis elegans. The worm reaches a length of about one millimetre (Image: ist/HeitiPaves).

Fig. 2: Maximum intensity projections of 3D images of the early unperturbed embryo of C. elegans. Maximum Intensity Projection (MIP) is an image processing technology commonly used in medical diagnosis (Images: Matthias Weiss).

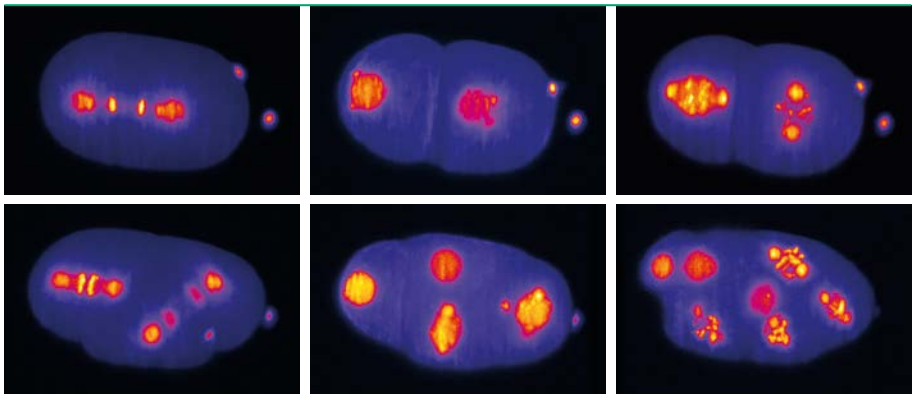

Fig. 3: Fluorescence microscope image of a wild-type hermaphrodite of C. elegans. The nematode was treated with a fluorescent DNA stain to highlight the cell nuclei (Source: wikimedia commons / CC-BY-2.5).

phrodites that can produce around 300 offsprings in a completely autonomous fashion. Protected by an engulfing chitin eggshell, C. elegans develops from a fertilised egg (the zygote) to a first larval state that hatches upon reaching 558 cells. Strikingly, all body axes of the adult worm are already determined after the first three divisions of the zygote: the head-tail axis (anterior-posterior axis), the belly-back axis (dorsal-ventral axis), and the left-right axis.

Light-sheet microscopy makes it possible to follow the early stages of embryogenesis with high resolution in three dimensions over time. Already before the first cell division, for instance, one can observe the progressive emergence of an uneven distribution of the protein species PIE-1 and MEX-5 in the liquid cell interior of the ellipsoidally shaped zygote. In fact, PIE-1 and MEX-5 accumulate at opposite cell poles, and these opposing biochemical gradients eventually define the anterior-posterior axis of the worm. In this process, the accumulation of PIE-1 in the posterior end is a critical determinant for the emergence of a specialized daughter cell that will act as the precursor of the germ line.

At first glance, these processes seem to be so much pre-determined that no uncertainty is left. However, it is unclear why the two types of protein accumulate at opposite cell poles in the first place. Doesn't experience show that solutes tend to disperse in a liquid by diffusion, for example milk in coffee? Somewhat counterintuitive, the solution to this problem indeed relies on the diffusion movement of proteins, which is determined by fluctuations: With fluorescence correlation spectroscopy, one can see in high resolution how fast PIE-1 and MEX-5 proteins move within the zygote. Both protein species are observed to diffuse slower in the areas of their respective accumulation, while being faster in the middle of the zygote. Based on this experimentally obtained information, it is possible to understand and predict by means of a rather simple mathematical equation that the two proteins have to segregate in the cytoplasm and eventually concentrate at opposing poles of the zygote.

"Uncertainty is a constant companion in everyday laboratory life."

An even deeper understanding of this gradient formation in the zygote can be achieved by comparing the fluctuation-driven movement of proteins and their mutually inhibiting effect with predictions formulated mathematically by the British physicist Alan Turing in 1952. Under certain conditions, the combination of fluctuations, reactions, and diffusion cause a pattern, e.g. an accumulation of certain proteins at one cell pole. Today, we refer to these spontaneous patterns as "Turing patterns". The self-organisation process which sets the first body axis of the developing embryo is basically such a Turing pattern, that emerges by uncertainty, i.e. by fluctuations.

On larger length and time scales, starting from the *C. elegans* zygote, a series of cell divisions is observed in all of which the total embryonic volume is maintained and in which the emerging cells slide into seemingly predetermined positions. At this early stage of the worm's development, it seems as if the organism runs on autopilot and knows exactly what to do. The freedom to develop alternatively and any uncertainties appear to be eliminated. Yet, when comparing different embryos, one can still observe slight variations in cell positions, even though there seems to be a dominant driving force that largely overrides these small uncertainties.

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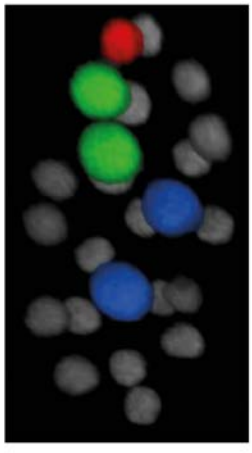

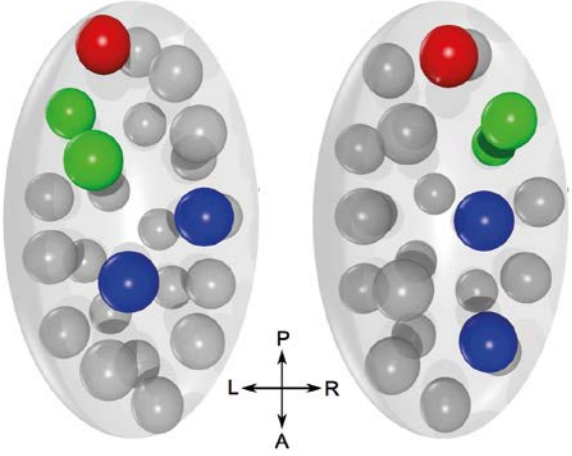

Fig. 4: Unerturbed arrangement of cells in the ellipsoidal eggshell of the nematode C. elegans (left). It compares favorably to computer simulations of the undisturbed embryonic development (centre). However, if a disturbed development is simulated, cells show significant spatial deviations (right) (Images: Matthias Weiss).

If one determines the cell positions in the developing embryo over time experimentally, taking into account that new cells are constantly added, one can identify this guiding force with the help of simple model simulations: Mechanical cues dictate which positions have to be assumed by cells within the ellipsoidally shaped rigid eggshell. In particular, each cell seeks the position of least constraints, i.e. those loci where it experiences the least pressure from neighbouring cells and the eggshell. This is most obvious after the first two division cycles, when the embryo consists of just four cells. In perturbed embryos that do not have a chitin eggshell, cells arrange themselves as spherically as possible, namely as a tetrahedron. In the native case, however, the repulsive forces of the ellipsoidal eggshell push cells to a planar arrangement which supports a correct morphology in subsequent steps of development.

Concomitant to this mechanical guiding, also the timing of the sequence of cell divisions is fairly regular. It turns out that cell division times are inversely proportional to the volume of the mother cell, i.e., the smaller the cells of the embryo become, the longer it takes until the next division takes place. In this way, the increasing complexity of the embryo is given enough time so that new cells can relax to their preferred position and do not end up at wrong loci. This coupling of cell size and division time can again be explained with a fairly simple and plausible physical mechanism.

Does this now mean that all uncertainty has disappeared, at least in the early embryogenesis of *C. elegans*? Ultimately not, because individual embryos still show significant fluctuations around the "mean behaviour" that can be derived for an ensemble of individuals. Moreover, one important random factor, the so-called "biochemical noise", is not yet included in the predictions based on mechanical cues and hence a number of fluctuation sources, from transcribing genes to the production and degradation of proteins, will contribute an additional layer of uncertainty and complexity. Therefore, uncertainty remains a constant companion – and it will continue to be the task of science to identify and address this challenge.

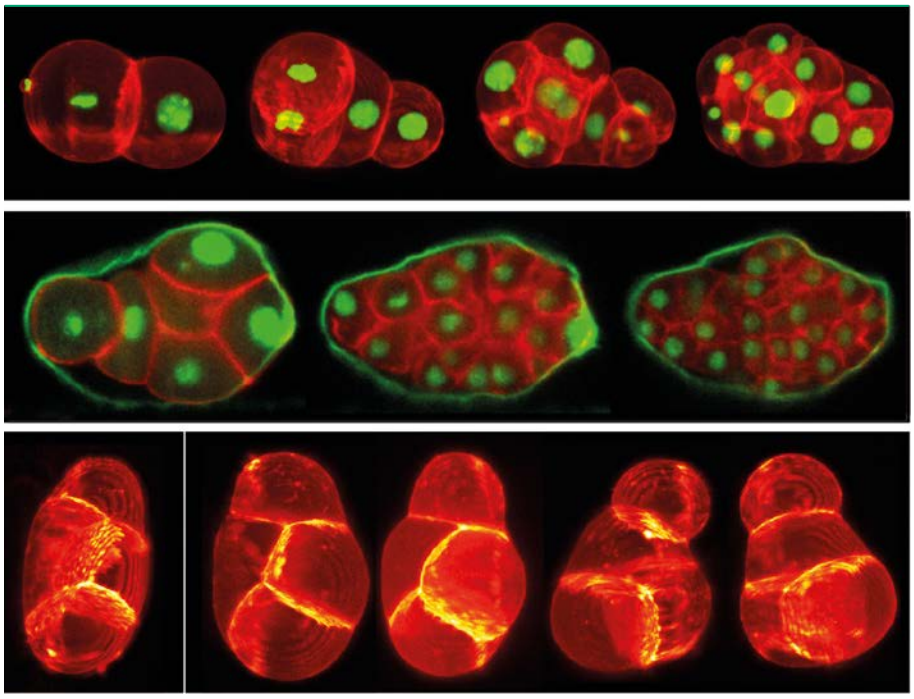

Fig. 5: Light sheet micrographs of embryos lacking a chitin eggshell, leading to an altered cell arrangement (Images: Matthias Weiss).

Fig. 6: Prof. Dr. Matthias Weiss (centre), Sebastian Krauß M.Sc. (left), and Rebecca Benelli M.Sc.(right) check on a C elegans colony on an agar plate (Photo: Christian Wißler).

RECOMMENDED READING

R. Benelli, P. Struntz, D. Hofmann, M. Weiss: Quantifying spatiotemporal gradient formation in early Caenorhabditis elegans embryos with lightsheet microscopy, Journal of Physics D (2020), 53, 295401. DOI: 10.1088/1361-6463/ab8597.

R. Fickentscher, S.W. Krauß, M. Weiss, Anti-correlation of cell volumes and cell-cycle times during the embryogenesis of a simple model organism. New Journal of Physics (2018), 20, 113001. DOI: 10.1088/1367-2630/aaea91.

1 R. Benelli et al.: Journal of Physics D (2020), see Recommended Reading.
2 R. Fickentscher, P. Struntz, M. Weiss: Mechanical Cues in the Early Embryogenesis of *Caenorhabditis elegans*. Biophysical Journal (2013), 105, 1805. DOI: 10.1016/j.bpj.2013.09.005. – R. Fickentscher, P. Struntz, M. Weiss: Setting the Clock for Fail-Safe Early Embryogenesis. Phys. Rev. Lett. (2016), 117, 188101. DOI: 10.1103/PhysRevLett.117.188101.
3 R. Fickentscher et al: New Journal of Physics (2018), Recommended Reading.

Stefan Knauer

Science in crisis?

A European initiative develops solutions

Examination of the folding state of a protein for quality control using nuclear magnetic resonance (NMR) spectroscopy (Photo: Jürgen Rennecke).

In medicine as well as in the natural sciences, life sciences, engineering, social sciences, and the humanities, reproducibility is a cornerstone of empirical research. At the same time, it is a central requirement of good scientific practice. Depending on the discipline, the term "reproducibility" has a slightly different meaning, but it generally describes the fact that a certain process can be repeated any number of times, each time leading to the same result. In the natural sciences, this means that the findings obtained in an experiment can only be considered trustworthy if they are reproducible under the same conditions (in independent laboratories). Only in this case can a degree of certainty be achieved that

is necessary to be able to responsibly apply research results, for example, in medicine or in new technological developments. Accordingly, there is a public interest in safeguarding scientific findings, in identifying non-reproducible results, and in detecting deliberate falsification.

However, reproducibility is not a general criterion of scientific knowledge or even of good science. There are, for instance, numerous fields of research that study unique events such as a volcanic eruption or stellar explosions, or that deal with phenomena that cannot be observed repeatedly for technical or financial reasons. Moreover, the finding of reproducibility or non-reproducibility of a certain research result is a scientific result in itself, and proven non-reproducibility is not *per se* an indication of bad science. However, this fact should not be used as an excuse for non-reproducibility if the reproducibility of a scientific result is methodologically expected.

The problem

For some time now, preclinical research, which represents an important link between biomedical and pharmacological basic research and its clinical application and further development, has been having a problem with the reproducibility of research results. In particular, a publication in 2012 on the lack of reproducibility of preclinical studies in cancer research [1] and a series of articles in *the Lancet*, one of the oldest and most prestigious medical journals, in 2014 helped to reignite the debate. Numerous other articles followed, and a 2016 survey of around 1500 scientists by the journal *Nature* found that 70 per cent of respondents had failed in their attempts to reproduce experiments conducted by other research groups. Furthermore, 90 percent of the respondents confirmed that science was in a crisis.[2] This "reproducibility crisis" encompasses a wide range of disciplines in the natural sciences, including medicine and biomedicine.

If one pursues the problem of lack of reproducibility further, one inevitably comes up with the questions "Are most published research results wrong?" and "Doesn't this cause immense costs?" A 2015 study attempted to estimate these costs, based on "only" a 50 per cent non-reproducibility rate. The authors report that the US alone invests 56.4 billion US dollars per year in preclinical research, of which around 28 billion is spent on non-reproducible research.[3] These facts are worrying and highlight the need for action.

In addition to researchers, scientific journals and funding agencies, such as the German Research Foundation (DFG) or the National Institutes of Health in the USA, have now openly acknowledged the crisis and begun to respond. The national and international debate shows that self-monitoring in science is also taken seriously with regard to the reproducibility of research results, and is understood as a pressing challenge, because the reproducibility crisis endangers both the performance of research itself and society's trust in it. However, the debate shows just as clearly that the basic idea of scientific research – namely that it is able to monitor itself and developing further on the basis of reproduced results – remains in force despite the current problems.

"In order to maintain, and possibly increase, confidence in science and its quality, current efforts to counteract the lack of reproducibility should be given the highest priority."

Causes of poor reproducibility

The reproducibility crisis results from a confluence of a wide variety of causes, which vary in their degree of importance across disciplines. The most common and important causes are:

- *Competitive and publication pressure:* Researchers face an ever-increasing competitive and publication pressure. The careful planning, preparation, performance, and evaluation of experiments, as well as the subsequent publication of the results, requires personnel, financial resources, time, and opportunity – all of which are parameters that stand in stark contrast to the increasing pressure to compete, succeed, and accelerate progress. In addition, attempts to repeat the results obtained in previous experiments in the original laboratory or elsewhere (so-called replication studies) are often expensive, tie up resources, and are less attractive from a publication perspective than publishing results obtained for the first time.

- *Inadequate protocols, selective publication, and limited access to literature:* Experiments that led to the first published research results are often only inadequately described in the corresponding publication – among other things because they were inadequately logged. Furthermore, often not all raw

Fig. 1: The reproducibility crisis (Graphic: Stefan Knauer).

data collected in the course of a study are actually analysed and/or published. It is not uncommon for a desired research result to influence the selection and publication of data. In addition, access to many scientific journals or individual articles is subject to a fee. Thus, many scientists are denied access to the original publications and the experimental descriptions contained therein for financial reasons.

- *Quality deficiencies in the experiments:* The design or conduction of the experiments from which the research results have emerged turn out to be inadequate in some cases. Questionable, inappropriate, or inadequate methods have been used, due to lack of expertise, time pressure, lack of access to certain instruments, or insufficient professional supervision, among other reasons.

Fig. 2: Investigation of the homogeneity of a protein sample for quality control by analytical size exclusion chromatography (Photo: Jürgen Rennecke).

- *Quality deficiencies in equipment, biological reagents, and reference materials:* Over and over it is found that the equipment and instruments used either have not been operated correctly or have not been calibrated correctly or at all, respectively, with reference materials of inferior quality or a lack of know-how being often responsible for faulty calibration. Another serious deficiency is often the poor quality of the biological reagents used, for example purified proteins.

What can be done? European initiatives seek answers

Scientists, editors of scientific journals, research institutions, scientific organisations, and funding bodies are all aware of the problem in its full extent. For some time now, there have been efforts at national and international level to do something about it. For example, "open access" journals and "open access" initiatives are intended to make literature freely available to everyone. In addition, many journals and public databases have now established high standards for certain methods, for instance statistical analyses. In addition, initiatives such as the National Institutes of Health's "NHI Rigor and Reproducibility Initiative" have been launched. Thanks to these actions, significant improvements have already been noted. However, many initiatives aimed at counteracting the "reproducibility crisis" had only limited success, or tend to be local or subject-specific efforts that are not aimed at the scientific community as a whole.

One initiative that aims, amongst other things, to develop and establish approaches to solving the crisis on a broad international level is the European network "Association of Resources for Biophysical Research in Europe (ARBRE)". It was launched in 2014 by Patrick England (Institut Pasteur, France) and Thomas Jowitt (University of Manchester, UK) to bring together experts and research institutions in the field of molecular biophysics from all over Europe. An innovative, open, and interdisciplinary network was created. The establishment of the network was acknowledged and was funded by the European Cooperation in Science and Technology (COST) from 2016 to 2020. During this time, the network gained international recognition under the acronym "ARBRE-MOBIEU" (MOBIEU: Molecular Biophysics in Europe). It finally brought together more than 400 researchers from around 150 institutions in 30 European countries, who used the network to combine

and share their expertise on a common platform. One of the network's seven working groups was dedicated to the challenge of optimising the quality of scientific data. It was led by Stefan H. Knauer (University of Bayreuth) and Margarida Bastos (University of Porto, Portugal), and pursued various approaches to achieve this goal:

■ Purified proteins play an important role in many areas of research, but clear standards for the quality control (QC) of these biological reagents are lacking – or, where established standards exist, they are not sufficiently implemented. As a result, poor quality peptides and antibodies are used in preclinical research, for example, which not only compromises the overall quality of research but also incurs high costs. According to one estimate, 36 per cent of preclinical non-reproducible results in the USA are directly attributable to the inadequate quality of biological reagents and reference materials, which equates to around 10.8 billion US dollars annually.[4]

■ More than ten years ago, the European network "Protein Production and Purification Partnership in Europe (P4EU)" attempted to establish standards for the QC of purified proteins, but without any great, lasting success. Moreover, there are currently only a few scientific journals and databases that oblige their authors to deposit QC data for the proteins used in their research. Therefore, a group of ARBRE-MOBIEU members, including Stefan H. Knauer, joined forces with representatives of P4EU. This gave fresh momentum to the initiative to establish and enforce uniform standards and new ideas and concepts were developed. The scientists first set up general guidelines for QC of purified proteins. These guidelines describe simple tests that enable a reliable quality check of the reagents to be used. They were acknowledged in both networks and have since been implemented, disseminated, and supported by an extensive list of signatures. The guidelines were also recently published in *Nature Communications*; together with the recommendation that all future publications and grant proposals in the field of life sciences should include QC data for all relevant protein-based reagents in each case.[5] A recent study published in *the European Biophysics Journal* shows that following these QC guidelines improves the reproducibility of experiments and increases confidence in their results.[6]

■ Another approach of the working group is standardisation. The basic prerequisite for high data quality, reproducibility, and comparability is that experiments using a certain technique are carried out according to a standardised procedure. Standardisation should avoid systematic errors that falsify the measurement result, and it should ensure that experiments are carried out in the same way in different research groups. Currently, there are still very different experimental protocols for many techniques in the field of biophysics, which, in turn, are individu-

RECOMMENDED LINKS

Homepage of the ARBRE association (under construction):
https://www.arbre-biophysics.eu/

Homepage of the ARBRE-MOBIEU European network:
https://arbre-mobieu.eu/

Homepage of the MOSBRI European network:
https://www.mosbri.eu/

Quality control of purified proteins

The guidelines, which were developed by members of the European networks "ARBRE-MOBIEU" and "P4EU", include the following requirements in particular:

1. *Minimum standards for information on proteins:* For each protein used, at least the following data should be available:
   - complete sequence
   - precise production and storage conditions
   - the method for determining the concentration
2. *Minimum QC standards:* These QC criteria should at least be met before working with the protein. They can be assessed with simple, widely used methods:
   - purity, e.g. checked by sodium dodecyl sulphate-polyacrylamide gel electrophoresis
   - homogeneity/dispersity, e.g. checked by analytical size exclusion chromatography or dynamic light scattering
   - identity, e.g. checked by mass spectrometry
3. *Extended QC criteria:* in addition to the minimum QC criteria to be fulfilled, the target protein can be further characterised with regard to its quality, for example with regard to its folding state or its specific activity.

Further information: **https://arbre-mobieu.eu/guidelines-on-protein-quality-control/**

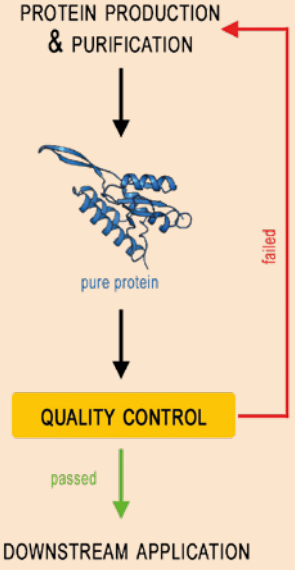

Fig. 3: Scheme of the guidelines established by ARBRE-MOBIEU and P4EU for quality control of purified proteins (Graphic: Stefan Knauer).

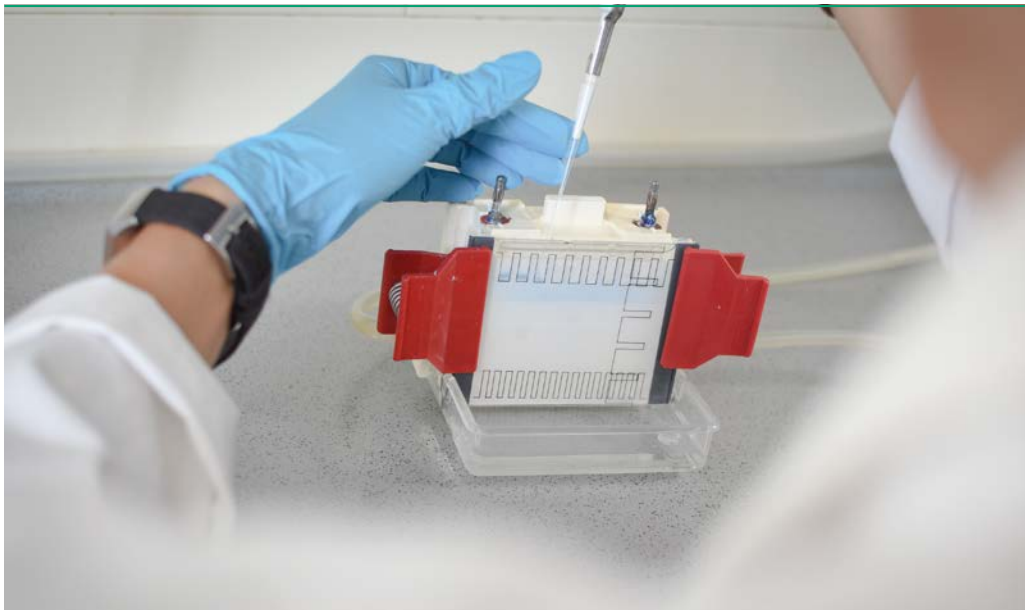

Fig. 4: Investigation of the purity of a protein sample for quality control by means of sodium dodecyl sulphate polyacrylamide gel electrophoresis (Photo: Jürgen Rennecke).

alised and adapted by laboratories. For a number of techniques, the working group has developed "Standard Operation Procedures" (SOPs), which have been reviewed and accepted throughout the ARBRE-MOBIEU community. Since then, they have been successfully used by the member institutions and disseminated in the scientific community to hopefully establish them as a general standard. So far, SOPs exist for about 15 techniques, which are freely accessible and are, in part, also published in journals.[7]

In order to achieve high reproducibility and comparability, standard/model systems for research techniques and reagents for calibrating instruments must meet high standards. A survey within ARBRE-MOBIEU revealed that there is a strong need for new standard systems that are as versatile as possible, especially for techniques to study molecular interactions. A first new system for interaction studies has already been developed and has proven to be very promising.[8]

In order to be able to make statements about the reproducibility, comparability and reliability of research results, benchmarking studies can be performed. These are broad comparative studies conducted with standardised test/model systems. The working group in the ARBRE-MOBIEU network has conducted three such studies so far. One of these studies, dealt with a relatively new technique, *Microscale Thermophoresis (MST)*, which is used to investigate interactions between biomolecules.[9] Two test systems were tested in more than 40 laboratories in Europe and the USA.

Other ARBRE-MOBIEU working groups have also developed initiatives to increase data quality. In international training courses, renowned experts from different disciplines taught participants new research methods and approaches in biophysics. In addition, many scientists have been given the opportunity to visit research institutes in other European countries and benefit from their expertise and equipment. ARBRE-MOBIEU has also collaborated very successfully with developers of biophysical instruments. The common goal was to adapt and optimise equipment and methods to the needs of the scientific community.

New initiatives

ARBRE-MOBIEU has now given rise to two new initiatives that further develop and expand the basic ideas of ARBRE-MOBIEU. On the one hand, the inde-

RECOMMENDED READING

A. de Marco et al.: Quality control of protein reagents for the improvement of research data reproducibility. Nature Communications (2021), 12, 2795. DOI: 10.1038/s41467-021-23167-z.

B. Raynal et al.: Assessing and Improving Protein Sample Quality, in: T. Daviter et al. (eds.): Protein-Ligand Interactions : Methods and Applications. New York : 2021, 3-46 . DOI: 10.1007/978-1-0716-1197-5_1.

1 C.G. Begley, L.M. Ellis: Drug development: Raise standards for preclinical cancer research. Nature (2012), 483, 531-533. DOI: 10.1038/483531a.
2 M. Baker: 1,500 scientists lift the lid on reproducibility. Nature (2016), 533, 452–454. DOI: 10.1038/533452a.
3 L.P. Freedman: The Economics of Reproducibility in Preclinical Research. Plos Biology (2015). DOI: 10.1371/journal.pbio.1002165.
4 Ibid.
5 A. de Marco et al.: Nature Communications (2021), see recommended reading.
6 N. Berrow et al.: Quality control of purified proteins to improve data quality and reproducibility: results from a large-scale survey. European Biophysics Journal (2021), 50, 453-460. DOI: 10.1007/s00249-021-01528-2.
7 https://arbre-mobieu.eu/sops-wg4/
8 H.L Birchenough, H.D.R. Nivia, T.A. Jowitt: Interaction standards for biophysics: anti-lysozyme nanobodies. European Biophysics Journal (2021), 50, 333-343. DOI 10.1007/s00249-021-01524-6.
9 B. López-Méndez et al.: Reproducibility and accuracy of microscale thermophoresis in the NanoTemper Monolith: a multi laboratory benchmark study. European Biophysics Journal (2021), 50, 411-427. DOI: 10.1007/s00249-021-01532-6.

Molecular-Scale Biophysics – Biophysics on the molecular scale

In this dynamic and interdisciplinary research field, biological (macro)molecules and their complexes are studied. Systems are characterised on a scale between structural descriptions at the atomic level and observations at the cellular level ("between atom and cell"). "Molecular-scale biophysics" has significant applications in basic research, biomedicine, and drug development. Methods from the fields of spectroscopy, hydrodynamics, real-time microfluidics, and thermodynamics, as well as single-molecule techniques are used and even combined with each other.

pendent association "ARBRE" was founded on July, 1st 2021, with Adriana E. Miele (University of Lyon, France) as President and Stefan H. Knauer (University of Bayreuth) as Vice President. On the other hand, the consortium "Molecular-Scale Biophysics Research Infrastructure (MOSBRI)", which is funded as an EU infrastructure project from the EU Framework Programme "Horizon 2020", started at the same time.

Prospects

Reproducibility and reliability of research data are essential cornerstones of scientific research. In order to maintain, and possibly increase, confidence in science and its quality, current efforts to counteract the lack of reproducibility should be given the highest priority. Based on the promising approaches of ARBRE-MOBIEU, ARBRE and MOSBRI are steadily expanding this commitment, with the common goal of optimising data quality in scientific research in Europe and beyond, and, in particular, advancing biophysics as a cutting-edge discipline.

AUTHOR

Dr. Stefan H. Knauer is a post-doctoral researcher in the Biochemistry IV - Biopolymers research group at the University of Bayreuth.

Fig. 5 : Investigation of the folding state of a protein for quality control using circular dichroism spectroscopy (Photo: Jürgen Rennecke).

Anna Schenk
Viktoria Grün

Research following Nature's recipe book

From biogenic minerals to new energy materials

Chambered nautilus (Photo: ist).

Biogenic minerals are materials with sophisticated self-organised structures that are perfectly adapted to their respective functions - for example, in terms of their mechanical stability or their structure-related colour effects. These complex architectures can be interpreted as answers to material science problems that Nature has found in the course of evolution according to the principle of "trial and error". This principle plays a central role in materials science - for example, when it comes to the design and synthesis of materials that must have dedicated properties to be suitable for intended technical applications under defined conditions. In the face of such a challenge, much is uncertain, even if the research work to develop the targeted materials can usually start from a broad foundation of established knowledge.

The following article aims to show by means of a few examples that a look at biological mineral systems can substantially promote the process of researching and developing new functional materials. Evolution has, pre-empted science with regards to the principle of "trial and error" and has equipped living organisms with materials that are virtually tailor-made for their life and survival in their respective environment. In order to understand how Nature has found these answers, it is important to consider the specific requirements that have been fulfilled by the respective materials. "If bone is the answer, then what is the question?" was the title of an article published in 2000 by bioengineer Rik Huiskes, which dealt with the structure and biomechanics of vertebrate bones.[1] Only when the problem for which evolution has developed a solution is precisely identified can materials science learn from nature's recipe book.

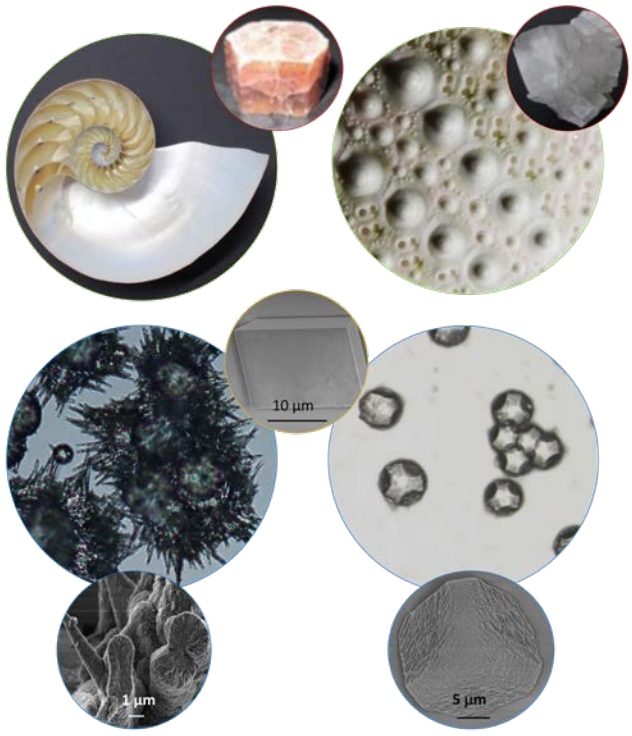

Fig. 1: Geological, biogenic, and synthetic calcium carbonate structures. Top left: Nautilus shell with shiny mother-of-pearl layer composed of aragonite; attached is a geological aragonite crystal. Aragonite is one of the three naturally occurring anhydrous crystalline modifications of calcium carbonate. - Top right: Sea urchin skeleton consisting of a porous calcite structure; attached is a geological calcite crystal. - Middle: Synthetically produced calcite single crystal. - Bottom: Bio-inspired calcite particles with unusual morphologies formed by crystallisation in the presence of polyvinylamine (left)[2] and of polysyrenesulfonate (right)[3] (Images: Anna Schenk).

Biominerals: Simple raw materials, complex architecture

Biogenic minerals - hereafter referred to as biominerals for short - usually consist of simple and readily available starting materials, for example the elements calcium, magnesium, carbon, oxygen, phosphorus, and sulphur. Although this implies a limitation in terms of their chemical composition, Nature is able to further develop and optimise the functional properties of the materials formed from these elements (Fig. 1). Geological mineral crystals, such as calcium carbonate ($CaCO_3$), which can appear in the form of calcite and aragonite modifications, among other crystal structures (Fig. 2), typically have a regular geometric shape with smooth external surfaces. This is due to the periodic arrangement of the atomic and molecular building blocks as if on a three-dimensional lattice. Many biominerals, on the other hand, exhibit curved surfaces and a complex hierarchical organisation. From the nanometre level to the macroscopic shape, their structure is optimised in such a way that the organization at each length scale contributes significantly to the functional properties of the material, for example to higher mechanical resilience.

In contrast to the formation of geological minerals, biomineralization is controlled by organic molecules. These can be insoluble in water and therefore act like a template for mineral deposition. However,

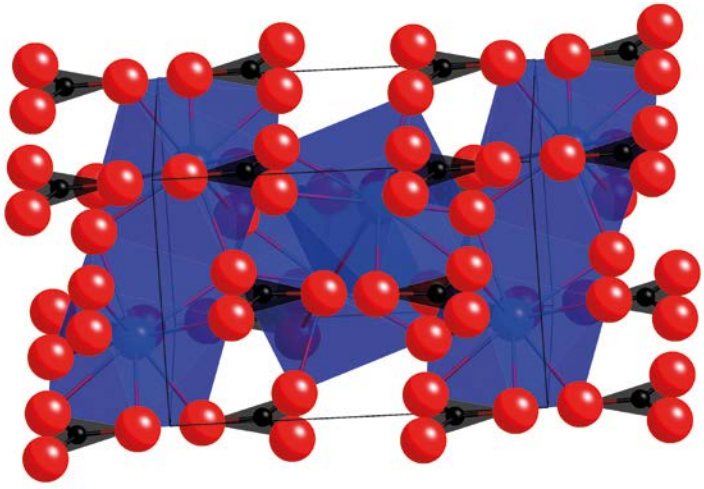

Fig. 2: Crystal structure of aragonite consisting of calcium (blue), oxygen (red), and carbon (black) (Graphic: Judge Nutmeg / wikimedia commons).

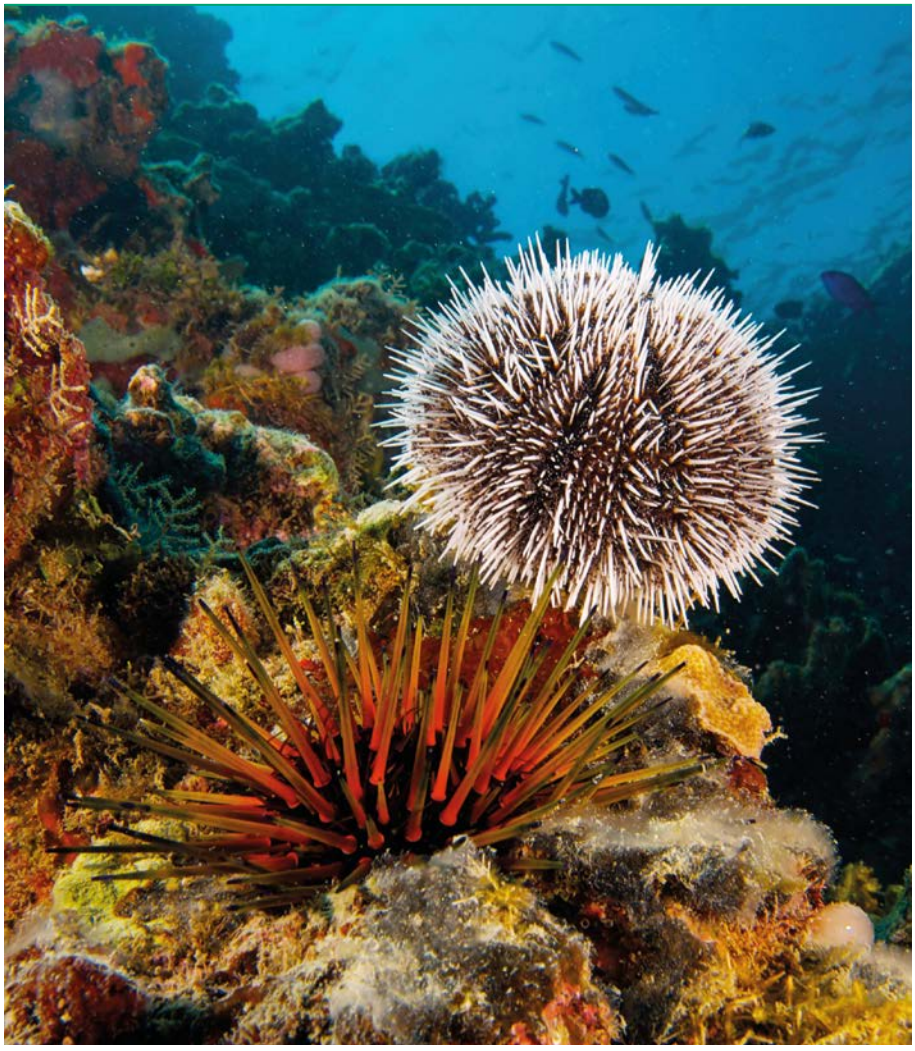

Fig. 3: Regular sea urchins Tripneustes ventricosus (top) and Echinometra viridis (bottom) in a reef. The skeleton of the sea urchins consists of calcite (Photo: Nick Hobgood / wikimedia commons).

they can also be soluble and interact with ions or initial aggregates at early stages of biomineralization. In this case, they may interfere fundamentally in the process of crystallization – for example, by directing an ordered self-assembly of the resulting mineral units. If the smallest residues of the organic molecules remain enclosed in the final crystalline structure, organic-inorganic hybrids are often formed. In some biominerals such "impurities" fulfil an important function, for example by making the material harder and more mechanically resistant.

On the nanoscale, biominerals, like the iridescent nacre of the nautilus, are often composed of perfectly arranged uniform mineral building blocks that are "glued together" by organic molecules. This brick-like structure makes it possible to realise arching, curved surfaces and complex shapes on the macroscopic scale. In the deposition of the smallest mineral units, only a few nanometres in size, the organism provides the required conditions under which exactly the crystal phase desired can form.

To produce complex shapes, many organisms first deposit amorphous precursors that only subsequently transform into the more stable crystalline phase. Such "unstructured" precursor compounds only exhibit a local order in the arrangement of ions. They can therefore adapt to the given shape of a template more easily than a crystal with smooth facets. In biology, mineralisation typically takes place in relatively small spaces (*compartments*). As a consequence, even the crystal structure of the mineral may develop differently than would be the case in a larger volume. Such a restriction of the mineralisation space can lead to the deposition of metastable mineral phases, which are short-lived under normal conditions and can hardly be isolated from bulk crystallization.

Bio-inspired Crystallization

With its sophisticated concepts for the formation, growth, and self-organisation of crystalline particles, which have been optimised over the course of evolution, Nature is able to produce highly functional materials under the respective environmental conditions (Fig. 3). The characteristic properties of biominerals are therefore a rich source of inspiration for many materials science research projects in which crystallisation phenomena play a role - for example, for the production of dental ceramics and construction building materials, but also in the preparation of functional materials with relevance for the transition to renewable energy.

In order to be able to technologically utilize the construction principles of biomineralization, it is first necessary to develop a sound understanding of the principles that underlie the formation of such structures. To achieve this, it is beneficial to look at biological systems in detail and to simultaneously study basic crystallisation mechanisms on model systems. For example, a single crystal of calcite, a biologically and geologically very widespread mineral, typically adopts the shape of a rhombohedron. But in the laboratory, the formation of structures that deviate profoundly from this regular shape can be readily induced. Examples of such a polymer-driven unusual structure formation in the laboratory are thistle-like particles with fibrous outgrowths (Fig. 1, bottom left)[2] and rounded crystals with a plate-like substructure (Fig. 1, bottom right).[3] In both cases, the

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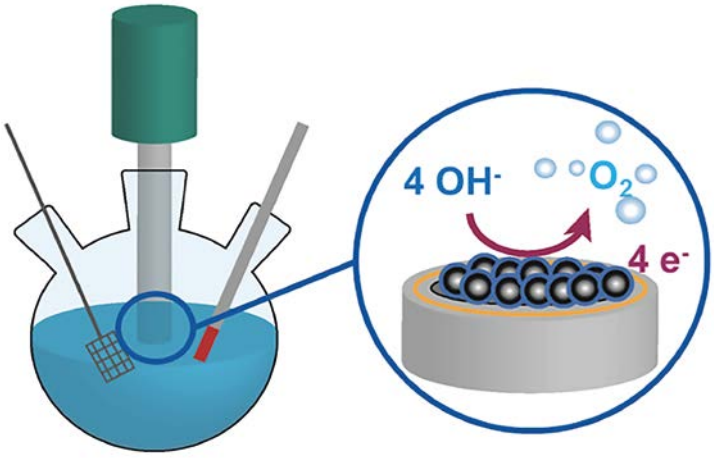
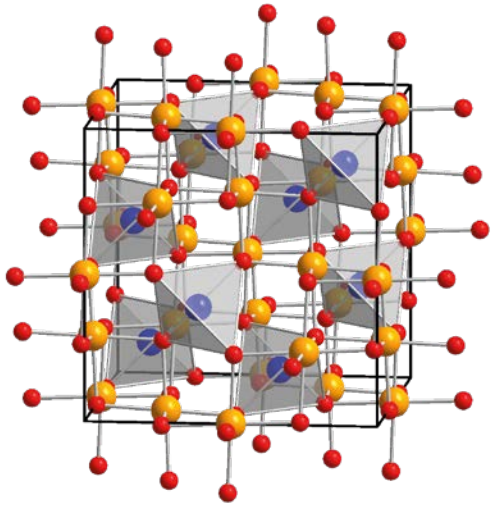


Fig. 5: Schematic illustration of an electrochemical cell. Co3O4 catalyst particles immobilized on the working electrode catalyse the anodic oxygen evolution, a partial reaction of water splitting (Graphic: Anna Schenk).

particles are deposited through non-classical crystallization phenomena, in which the final crystal is formed by an aggregation of amorphous or crystalline particles.

Novel superstructures for the electrocatalysis of water splitting

For several years, the research group of Prof. Dr. Anna Schenk has been intensively investigating the structuring of cobalt(II,III) oxide (Co_3O_4). Synthetically, this material can be obtained, among other routes, through a thermal conversion of cobalt hydroxide carbonates. These are precursor compounds that can be produced and processed from an aqueous solution. Co_3O_4 is an inorganic functional material (Fig. 4) with a wide range of applications, for example in battery technology or sensor technology. This compound can also be employed for heterogeneous catalysis, where the use of Co_3O_4 is particularly exciting in electrocatalysis when it is necessary to split water into its elementary components of hydrogen and oxygen (Fig. 5). This opens up new perspectives with regard to robust, efficient, and sustainable systems for the conversion and storage of energy - and thus also for the success of the energy transition.



One focus of the research work in Bayreuth is on the structure-property relationships in electrocatalysts. One example is mesoscale structural motifs that influence the electrocatalytic activity of Co_3O_4. To demonstrate this relationship, a facile room-temperature method was developed for the generation of cobalt hydroxide carbonate particles, which are composed of radially arranged platelets and are characterized as spherulitic due their hemispherical shape (Fig. 6).[4] These particles are converted to the Co_3O_4 phase by calcination. Over several length scales, down to the micrometre level, their morphology is preserved. At the nanoscale, however, the Co_3O_4 transforms into a superstructure of interconnected nanoparticles interspersed with a network of pores.

Electrocatalysts based on blueprints from Nature

The research group of Prof. Dr. Anna Schenk at the University of Bayreuth has set itself the goal of transferring fundamental concepts of biomineralization to the production of technologically attractive materials. In the field of electrocatalysis, the group's main focus is currently on the synthesis of cobalt(II,III) oxide (Co_3O_4). Complex hierarchical structures are to be generated at room temperature in particles of the precursor compound, cobalt hydroxide carbonate, which can subsequently be converted into the ca-

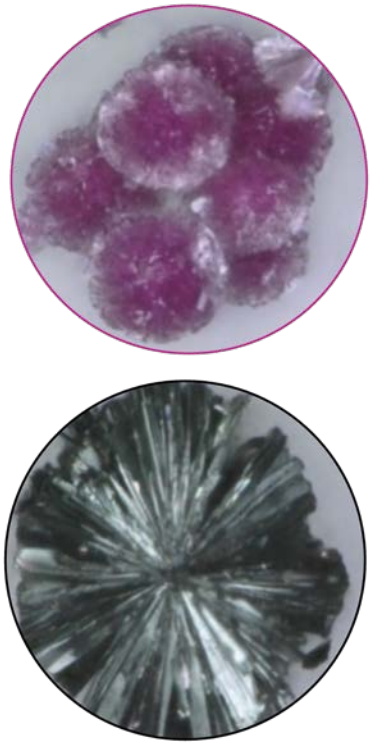


Fig. 6: Spherulitic cobalt hydroxide carbonate particles, before (top) and after (bottom) conversion into the functional Co3O4 phase[4] (Images: Anna Schenk).

Fig. 4 (left): Crystal structure of cobalt(II,III) oxide consisting of cobalt(II) ions (blue), cobalt(III) ions (orange), and oxygen (red) (Graphic: Andif1 / wikimedia commons).

Fig. 7: Left: Bio-inspired cobalt hydroxide carbonate structures. Deposition in the presence of tobacco mosaic viruses leads to microtubes consisting of a bioinorganic composite material. In the yellow circle: an enlarged view of the cross-section of a microtube and comparison with the dimensions of a single virus particle [5]. Centre: Self-coiling as a biological phenomenon: The spiralized structure of a pod. Right: Scanning electron micrograph of a self-coiled Co3O4 film [6] (Images: Anna Schenk & Viktoria Grün).

"The characteristic properties of biominerals are a rich source of inspiration for materials science research."

Fig. 8: Sea shells (Photo: ist).

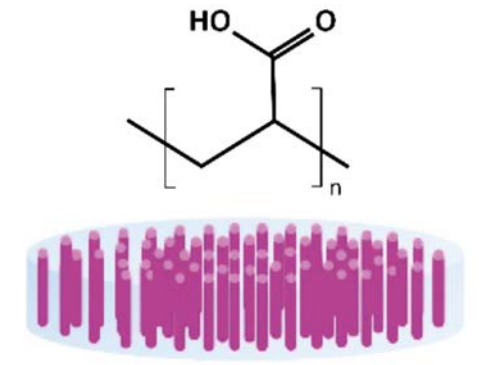
talytically active Co_3O_4. Previous research activities have led to promising results, as illustrated by the following examples:

- *Water-insoluble bio-templates.* In collaboration with a research group at the University of Stuttgart, tobacco mosaic viruses (TMV) were used to direct the bioinspired deposition of Co_3O_4. In the presence of Co^{2+} cations, the rod-shaped viruses undergo ordered assembly in the crystallisation solution. Mineralisation of these superstructures produces complex tubular bioinorganic composites of the TMV and the mineral.[5] By calcination, these microtubules can be converted into Co_3O_4. This again shows that the expression of functional properties is not solely determined by the chemical composition and the surface area of the catalyst material, but also depends onits mesostructure (Fig. 7).

- *Water-soluble additives.* In view of developing free-standing, compact electrodes with mesoscale channels, it has been possible to deposit mineral films in a gas diffusion process at the water/air interface of the reaction solution.[6] Further steps subsequently led to the creation of impressive spiralised Co_3O_4 structures. Such self-folding phenomena are common and well-studied in the plant kingdom. The extent to which they also occur in geological and synthetic mineral systems, however, is largely unknown (Fig. 7).

- *Structures on the sub-micrometer length scale.* Cylindrically shaped pores of polycarbonate membranes can be infiltrated with amorphous cobalt hydroxide carbonate in the presence of polyacrylic acid (PAA). The process of mineral deposition in the

channels, which have a diameter of less than one micrometre, depends largely on the concentration and molecular weight of the additive used. If the PAA polymer has a low molecular weight, the pore spaces are completely filled. Then, after dissolution of the template, smooth mineral fibres with a high aspect ratio can be isolated. However, if the polymer additive is a longer-chain PAA, short rods with a pronounced nanogranular fine structure are formed (Fig. 9).

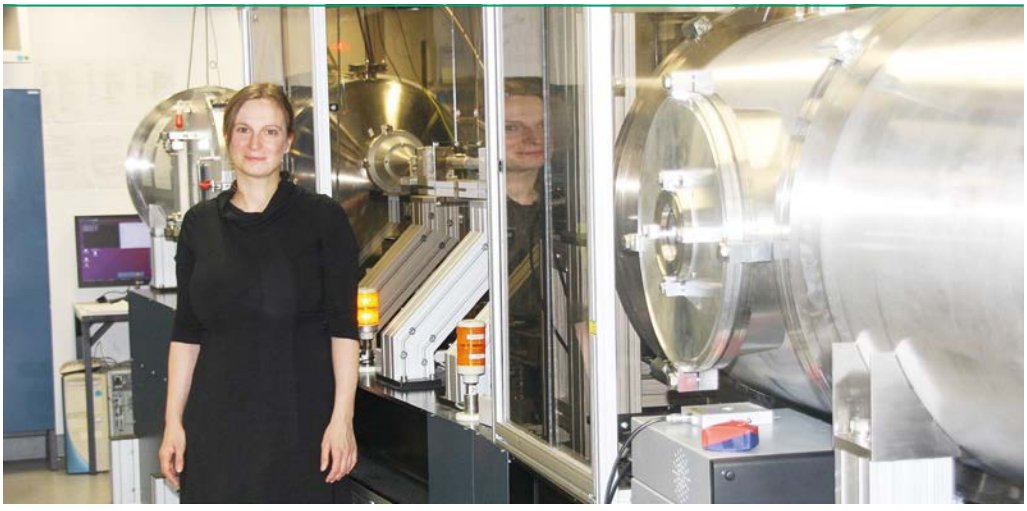


■ *Fig. 9: Rods and fibres in the sub-micrometre range. Top: Infiltration of the cylindrical pores of polycarbonate membranes (blue), with an amorphous cobalt hydroxide carbonate phase stabilised by polyacrylic acid (pink). After dissolution of the membrane, fibres with high aspect ratio (middle) or rods with nanoparticulate substructure (bottom) are formed, depending on the molecular weight and concentration of PAA molecules (Images: Viktoria Grün).*

Conclusion

The variability and the precision with which nature controls mineralisation processes are still unmatched in the laboratory. However, the study of biological mineralisation provides many starting points for the development of bio-inspired synthetic pathways that lead to new hierarchically structured materials and may be more environmentally friendly than conventional manufacturing processes. At the University of Bayreuth, these concepts are used to combine the complex architectures of biominerals with inherent functional properties of technologically utilized systems in the laboratory. Nature's "recipe book" serves as a guide. Referring to biologically inspired strategies can potentially reduce uncertainty regarding optimal synthesic routes, and in this respect help to prevent materials science research from being side-tracked.

■ *Fig. 10: Prof. Dr. Anna Schenk at the small-angle X-ray scattering facility of the Keylab "Mesoscale Characterization: Scattering Techniques" at the Bavarian Polymer Institute (BPI) (Photo: Christian Wißler).*



1 R. Huiskes: If bone is the answer, then what is the question? Journal of Anatomy (2000), 197(Pt 2), 145-156. DOI: 10.1046/j.1469-7580.2000.19720145.x.
2 A. S. Schenk et al.: Systematic Study of the Effects of Polyamines on Calcium Carbonate Precipitation. Chemistry of Materials (2014), 26 (8), 2703-2711. DOI: 10.1021/cm500523w. –in this the image of Calcite/Polyvinylamin particles used in Fig. 1.
3 A. S. Schenk et al.: Hierarchical Calcite Crystals with Occlusions of a Simple Polyelectrolyte Mimic Complex Biomineral Structures. Advanced Functional Materials (2012), 22 (22), 4668-4676. DOI: 10.1002/adfm.201201158 – in this the image of the Calcite/Polystyrolsulfonate particles used in Fig. 1.
4 A. S. Schenk et al.: Hierarchically Structured Spherulitic Cobalt Hydroxide Carbonate as a Precursor to Ordered Nanostructures of Electrocatalytically Active Co_3O_4. Crystal Growth & Design (2020), 20 (10), 6407-6420. DOI: 10.1021/acs.cgd.0c00576 – in this the images of the cobalt hydroxide carbonate particles and of the Cobalt(II,III)-oxide particles contained in Fig. 6.
5 A. S. Schenk et al.: Virus-directed formation of electrocatalytically active nanoparticle-based Co_3O_4 tubes. Nanoscale (2017), 9 (19), 6334-6345. DOI: 10.1039/C7NR00508C. In this the image of a microtube contained in Fig. 7.
6 V. Gruen et al.: Interface-mediated formation of basic cobalt carbonate/polyethyleneimine composite microscrolls by strain-induced self-rolling. Chemical Communications (2021), 57, 7244-7247. DOI: 10.1039/D1CC01136G. Herein, the SEM image in Fig. 7.

Christian Wißler

INTERVIEW WITH
FABIAN ELLER AND
JONAS LANDGRAF

On the scientific approach to uncertainty

A review of the 70th Lindau Nobel Laureate Meeting

Harbor entrance of Lindau, Lake Constance (Photo: ist).

From 27 June to 2 July 2021, you participated in the 70th Lindau Nobel Laureate Meeting as young physicists, which could only take place in an online format due to the pandemic. What do you remember most about it?

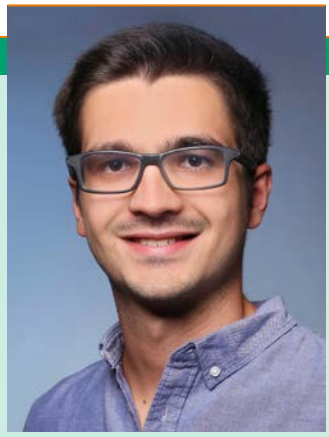
Fabian Eller: It was very impressive how lively the Nobel Laureates were, and how committed to this conference, and how interested they were in talking to us young scientists about new ideas in research. There were many small discussion groups and one-on-one conversations in which we could talk about our work in detail. There was a strong sense of personal involvement.

Jonas Landgraf: Walks along Lake Constance, boat trips, or Zeppelin flights, which are usually part of every Lindau Nobel Laureate Conference, unfortunately had to be cancelled this time. But because the conference was held online, many older Nobel Laureates logged on who would not have managed to fly to Europe if the conference had been held in person. Even the biochemist Edmond Fischer, who died a few weeks ago at the age of 101, was there. This meant that the research experience of many decades was represented at the conference.

In what contexts did the theme of "uncertainty" play a role during the conference?

J.L.: You have to distinguish between different aspects. First of all, in our personal exchanges, uncertainties about one's own academic career, and career planning were also discussed. The Nobel laureates reported on their own life paths and were able to give us one or two helpful pieces of advice. Quite independently of this, the question "Why trust science?" was discussed with regard to current developments. Today, a fundamental distrust can be observed among many people – not only in Europe, but also in the USA, where science was still perceived as the very foundation of the American nation in the 1960s and 1970s. There are certainly many reasons for this change. One reason could be that too often unrealistic expectations are placed on science, which it goes on to disappoint. This has also become clear in the pandemic. Many apparently believe that science can make concrete statements with certainty that affect people's lives in general. But in fact, based on different observations, theories, and their interpretations, it can only provide assessments that may later be limited or refuted by new findings.

F.E.: One has to take into account that scientific disciplines work on different scales. Microbiology, for example, gains new insights into how a virus behaves at the cellular level, but this does not mean that it is therefore competent to answer general questions about human life. To make such statements, research results from different disciplines would have to be brought together, and even then, it remains very difficult.



Fabian Eller M.Sc.

Fabian Eller M.Sc. is a doctoral student at the University of Bayreuth in Prof. Dr. Eva M. Herzig's Dynamics & Structure Formation group. Here he is currently working on organic semiconductors. The focus is on the investigation of nanostructures using X-ray scattering and the development of a novel methodology for influencing nanostructures. Parallel to his doctoral thesis, Fabian Eller is completing the elite study programme "Macromolecular Science" in the Elite Network Bavaria at the University of Bayreuth.

Jonas Landgraf M.Sc.

Jonas Landgraf is a doctoral student in the research group of Prof. Dr. Florian Marquardt at the Max Planck Institute for the Physics of Light in Erlangen, investigating how concepts in the field of machine learning can be transferred to physics. The question is how new insights can be gained with artificial intelligence. At the same time, Jonas Landgraf is taking part in the elite study programme "Biological Physics" in the Elite Network Bavaria at the University of Bayreuth.

Both participants in the 70th Lindau Nobel Laureate Meeting repeatedly took part in regional, national, and international physics competitions with great success during their school years. They were scientifically supervised at the Student Research Center (SFZ) of the University of Bayreuth. During their subsequent physics studies in Bayreuth, they were very successful here in their efforts to support pupils. The SFZ is an institution of the TechnologieAllianzOberfranken (TAO), in which the four Upper Franconian universities – the Universities of Bamberg and Bayreuth and the Universities of Applied Sciences of Coburg and Hof – cooperate.

Neither do the reasons why we can and should trust science not lie, or at least not primarily, in statements that reflect a current state of knowledge. Much more important are the tried and tested, rationally justified, internationally recognised procedures with which science achieves its research results. This in-

cludes, in particular, the constant willingness to modify or reject earlier statements in the light of new findings. And likewise, the ability to detach oneself from one's own prejudices and hopes in our scientific work, and to approach the respective research topics without bias. These are decisive criteria for the quality of science, and not a supposed irrefutability of its statements.

Were there any lectures or technical discussions during the conference that dealt with uncertainty in current research areas in physics?

J.L.: Yes, for example in the lecture by the Munich astrophysicist Reinhard Genzel, who was awarded the Nobel Prize in Physics in 2020 for the discovery of the supermassive black hole at the centre of the Milky Way. It was suspected that this black hole existed many decades ago, but it wasn't until 2018 that there was no other plausible explanation for the measurements obtained up to that point. Genzel showed that his discovery owed itself to the gradual exclusion of alternative explanations, and in this respect was the result of a continued reduction of uncertainty. And to this day there are unanswered questions that can never be answered. For we cannot fly into a black hole and make the necessary measurements - and even if we could, a return to Earth would be impossible. Another example is the Israeli biochemist Ada Yonath, who received the 2009 Nobel Prize in Chemistry for her research on the ribosome. For more than ten years, she persistently continued her research, against all doubts from her professional environment - until she was finally able to elucidate the first ribosome structures with the help of cryo-electron microscopy. In general, it has often been the case that laureates initially pursued their scientific interests as courageous individuals, and only later gained great esteem in the professional world.

"We only ever have access to a very limited section of the universe in which we can advance to new insights through measurement."

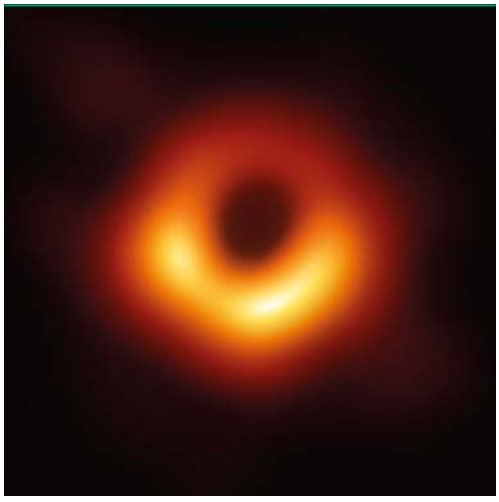


Fig. 1: Image created from radio readings of the Event Horizon Telescope showing the supermassive black hole of the galaxy M87 (Photo: wikimedia commons.).

F.E.: A fundamental physical question that will probably never be resolved and was repeatedly raised during the conference concerns quantum mechanics. There are two types of interpretations of quantum mechanics, which differ in how the theory is put in relation to the real world. In one case, the uncertainty of a measurement is understood as merely indicating the probability of an event occurring. In the other case, it is understood as the uncertainty of being able to identify the real world within an infinite number of possible worlds. Both interpretations are compatible with each other, and the statements obtained on their basis are equivalent. Consequently, it cannot be decided at all which interpretation is "true" or "false".

J.L.: Insofar as uncertainty is rooted in the fact that our knowledge has its limits, two types of uncertainty can be distinguished in physics. Firstly, the range of questions we can answer scientifically is limited by the power of the available research technology. However, technological progress can contribute to shifting these limits. For a long time, the resolution limit of microscopes defined by Ernst Abbe in the 19th century was considered insurmountable, but today there is super-resolution single-molecule spectroscopy, which can even measure the distances between individual molecules. But there are also limits to knowledge that nature sets for us. What goes on in the black holes of the universe, what happened before the big bang, and whether there is something beyond our universe that could be said to exist – these are all questions that we humans cannot answer in principle. We only ever have access to a very limited section of the universe in which we can advance to new insights through measurement.

How do these limits of knowledge influence scientists' attitudes towards their research?

F.E.: Anyone working in the natural sciences today who is aware of their own limitations knows the dynamics of scientific progress, and will be wary of presenting current findings as ultimate truths. There are always unanswered questions and very often there are alternatives that cannot be ruled out with absolute certainty - for example, when theories, models, or data can be interpreted differently. Even during the conference, a certain cautious attitude was noticeable among the Nobel laureates, but this was by no means in contradiction to their clearly noticeable openness to new, unusual ideas and research approaches.

J.L.: Good scientists are characterised by the fact that – when they publish ground-breaking discoveries, for example – they always name the unclear and uncertain points. They reflect on the conditions under which the model on which their research results are based would fail or need to be limited in its validity. Every model and every theory abstracts the real world to a certain degree, and it is always the task of a researcher to check to what extent it represents reality. This applies not least to natural constants, for example the gravitational constant, which describes the strength of gravitational force. The latest measuring techniques now allow us to determine the gravitational force between objects that are no heavier than one gram. Perhaps one day we will be able to determine the gravitational constant with even greater accuracy than today.

F.E.: At the same time – and this aspect is becoming increasingly important – the physics community is very careful not to prematurely announce sensational discoveries. Therefore, one tries to quantify the probability that must be reached so that one can assume with sufficient certainty that conspicuous features in a series of measurements are not based on random statistical fluctuations but have systemic causes. The so-called sigma values serve this purpose. In 2012, for example, the Higgs boson was detected at the CERN nuclear research centre in Geneva. This is a particle that gives other particles mass. Only when the scientists involved were able to declare it improbable to the value of "5-sigma" that the phenomena in question were due to statistical deviations, was the existence of Higgs bosons considered proven. And only then was the discovery awarded a Nobel Prize.

Is there a research direction in physics today that is working towards particularly exciting, perhaps even spectacular findings and developments?

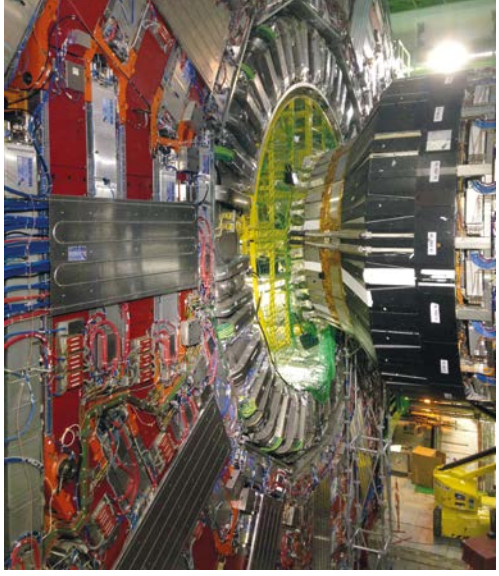


Fig. 2: The particle detector used at CERN in Geneva for the Compact Muon Solenoid Experiment (CMS), which is being used to research the Higgs boson (Photo: Tighef / wikimedia commons).

F.E.: Artificial intelligence is a forward-looking topic that is by no means only being worked on by computer science, but also in physics, for example. Increasingly in focus today is the question whether it is possible to create an artificial scientist who is capable of designing and conducting research, generating new knowledge, minimising ignorance, and assessing risks? Perhaps one day we will be able to delegate scientific research to such robotic beings – on a scale that seems unimaginable to us.

Is it difficult today to publish ideas and research results that venture into previously unknown territory in renowned international journals?

J.L.: The editors of these journals are usually interested in a high impact factor, which expresses how often the research they publish is cited in other scientific publications. It is therefore rightly considered a criterion for the influence of a journal in the scientific community. However, articles that start from very unusual research approaches or question traditional views from the ground up are not expected to receive a large or rapid international response. Often, a significant impact only emerges after many years. And in this respect, the editors tend to have little interest in publishing such contributions.

F.E.: In addition, there is the fear that one's own reputation will be damaged if the publication of unusual theses proves to be nonsensical or easily refutable. Thanks to the constantly growing number of open access journals, however, the situation has improved noticeably. The Lindau Nobel Laureate Meeting also made a contribution in this regard. During the 2018 meeting, Nobel Laureate Elizabeth Blackburn called on the 600 young scientists present to develop new ideas for "Open Science" – that is, for open, cooperative, and sustainable science. This ultimately resulted in the "Lindau Guidelines", which were presented at the 2021 anniversary conference and received broad support.

LINKTIPP

https://lindauguidelines.org/

Christoph K. Thomas
Alexander Schulz

Bringing light to the uncertain darkness of the polar night

Tracking the Arctic amplification of climate change

*Auroras are a rarity in Ny-Ålesund at 79 degrees latitude, and provided an impressive backdrop for the NYTEFOX Arctic experiment (Photo: Christoph Thomas). Small figure: The logo of **NY**-Ålesund **T**urbulenc**E** **F**iber **O**ptic e**X**periment", NYTEFOX for short (Design: Christoph Thomas).*

Man-made climate change is a fact. It has been demonstrably proven by a network of weather observations over long periods of time and all climate zones. The knowledge of changes in temperature, precipitation, and extreme events is irrefutable. But despite this certainty and the tangible impact of climate change on our daily lives, much is still uncertain. The processes that cause and continue to drive climate change are far from being sufficiently understood scientifically. This is particularly true for the polar regions of the northern and southern hemispheres, which are disproportionately affected by climate change. Understanding this phenomenon, known as "polar amplification", in more detail is indispensable in mitigating climate change and developing appropriate adaptation strategies.

Uncommonly complex: The boundary layer in the polar regions

Weather and climate models have proven themselves as virtual laboratories and hypothesis testers in climate research. However, the forecasts developed on the basis of these models cannot simply be transferred to the polar regions because agreement between the models is lower there than for other climate regions. The climatic processes are too specific at the poles, and there are only limited observation data available due to the difficulties of access. Exactly which models are particularly informative for understanding them is by no means clear as yet. This uncertainty is caused by an insufficient understanding of the biophysical transport of energy, heat, and carbon in the Earth's climate system. In this system, the atmospheric boundary layer plays a significant role. This is the lowest layer of the Earth's atmosphere, immediately adjacent to the Earth's surface. This layer of air, which is about 1.5 to two kilometres thick, connects all parts of the Earth's surface, contains almost the entirety of life over land, and is therefore often referred to as the "critical zone". At the poles, this boundary layer behaves fundamentally differently – due to the seasonal change between the polar night in winter and the polar day in summer – than in climatic zones that are exposed to sunlight for at least a few hours every day. Especially during the polar night, the boundary layer is more long-lived compared to its nocturnal equivalent at mid-latitudes, but also more sensitive to disturbance.

This sensitivity is due to the fact that in the atmospheric boundary layer of polar regions, many very different surfaces interact in a small space: open ocean with ice-covered sea surfaces and with land partly covered by vegetation, by snow, by frozen ground, or by liquid water. As a result, the interplay of transport processes in the near-surface air layer is unusually complicated. Moreover, these processes can amplify or weaken each other. In research, these interactions are referred to as feedbacks. For example, narrow cracks in the sea ice or small snow-free land areas can lead to disproportionate warming, melting, and evaporation over entire landscapes. Short-term disturbances can thus build up reciprocally and lead to abrupt changes.

NYTEFOX – a unique field experiment in the Arctic

This is exactly where the field experiment NYTEFOX comes in, the acronym standing for "NY-Ålesund TurbulencE Fiber Optic eXperiment". Cooperating in this research project are the Micrometeorology research group at the University of Bayreuth and the Physics of the Atmosphere research section at Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research (AWI) in Potsdam. During the transition period from the polar night into spring 2020, a joint team of a total of six scientists and students set off for the Svalbard archipelago (the historical name Spitsbergen was already officially changed in the Svalbard Treaty of 1925). The destination of the trip was the Franco-German AWIPEV research station in Ny-Ålesund on the 79th parallel. Ny-Ålesund is one of the northernmost year-round inhabited settlements in the world. Originally founded for

Fig. 1: NYTEFOX was a cooperation between the Micrometeorology research group at the University of Bayreuth and the Physics of the Atmosphere research section at Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research (AWI) in Potsdam. From left to right: Christoph Thomas (UBT), Alexander Schulz (AWI), Lena Pfister (UBT), Marie Zeller (AWI), Daniela Littmann (AWI), and Jannis Huss (UBT) (Photo: Jannis Huss).

RECOMMENDED LINKS

Homepage of the Franco-German AWIPEV research base, which is jointly operated by the Alfred Wegener Institute (AWI) and the French Institut polaire français Paul-Émile Victor (IPEV):
www.awipev.eu

Homepage of the international drift ice experiment MOSAiC, which has been led by the Alfred Wegener Institute (AWI) since autumn 2020:
www.awi.de/im-fokus/mosaic-expedition.html

coal mining, it has served as a base for international polar research since the 1960s. Here on Svalbard, NYTEFOX intended to shed light to the darkness of our understanding of the polar boundary layer, with the help of state-of-the-art fibre optic technology.

The key to the success of this unique experiment was the fact that the competencies of the two research partners complemented each other perfectly. The Micrometeorology research group at the University of Bayreuth is a world leader in the development and application of optical fiber-optic waveguides, which are used to measure temperature and wind. The AWI, in turn, as a Helmholtz Centre for Polar and Marine Research, has internationally outstanding infrastructure and logistics in just these fields.

Fig. 2: The main building of the station in Ny-Ålesund named after the polar explorer Carl Koldewey. Today it is integrated into the Franco-German research station AWIPEV. In front of it is a monument in honour of the polar explorer Roald Amundsen (Photo: Christoph Thomas).

Fig. 3 (below): NYTEFOX used the largest polar network of fibre optic cables to date to measure temperature and wind for research into near-surface transport processes (Photo: Harald Sodemann).

Both partners had already collaborated on the FLYFOX-A ("FLYing Fiber Optic eXperiment - Arctic") experiment in autumn 2018. This involved installing fibre optic technology on a tethered balloon and testing it in the Arctic for the MOSAiC International Drift Ice Expedition. The NYTEFOX experiment now focused on the question of which transport processes lead to the exchange of energy and heat in the uniquely cold landscape at Kongsfjord on Svalbard. New insights into these processes are crucial in advancing towards a better understanding of the atmospheric boundary layer in the Arctic. In addition, NYTEFOX aimed at overcoming two other uncertainties. The researchers were seeking to find out whether optical fibre technology could withstand the extreme conditions of the Arctic polar night, and they hoped to gain clarity on whether the fibre optic networks could be safely built and operated in the strictly protected Arctic ecosystem on Svalbard.

The special feature of NYTEFOX's design was that it combined several research technologies:

RECOMMENDED READING

M.-L. Zeller et al.: The NY-Alesund TurbulencE Fiber Optic eXperiment (NYTEFOX): Investigating the Arctic boundary layer, Svalbard. Earth System Science Data (2021), 13(7), 3439-3452. DOI: 10.5194/essd-13-3439-2021.

Fig. 4: Dawn over the Kongsfjord on Svalbard: As a result of the simultaneous occurrence of open water, sea ice, and land with snow, vegetation, and glaciers, the transport of heat and energy in the Arctic climate system is particularly complicated (Photo: Christoph Thomas).

- A network of optical fibres using a novel technology called "Fibre-Optic Distributed Sensing (FODS)" or "Distributed Temperature Sensing (DTS)". Thanks to this technology, the measurement of temperature in the air, snow, and water can be combined with the simultaneous measurement of air movement – with a high temporal (within a range of seconds) and spatial (within a range of decimetres) resolution over several hundred metres. These capabilities make it possible to visualise individual temperature signals and air movements that are difficult or impossible to detect with conventional point measurement methods.

- Ultrasonic anemometers and ground-based sound remote sensing technology conventionally used to measure wind speed at selected points.

The network of fibre optic cables built in the NYTEFOX project is the largest of its kind deployed in Arctic climate and weather research to date. Actually, the construction work was a tour de force in itself, and lasted a total of 14 "nights". They were initially hampered by colder than average air temperatures of minus 30 degrees Celsius at the beginning of February 2020. It was only towards the end of the experiment in mid-March that milder temperatures of around minus ten degrees Celsius set in. The research station is not far from the North Pole, but because of its proximity to the Arctic Ocean, the air

Fig. 5: Disturbing the sensitive Arctic ecosystem on Svalbard was avoided at all cost. The reindeer on site stayed clear of the measurement setup and grazed peacefully outside the fibre optic cables (Photo: Christoph Thomas).

AUTHORS

Prof. Dr. Christoph Thomas is Professor for Micrometeorology at the University of Bayreuth.

Dr. Alexander Schulz is member of the Physics of the Atmosphere research section at Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research (AWI) in Potsdam.

temperatures here are comparatively mild. In January, they range between minus 17 and minus four degrees Celsius in the long-term average.

Research in the polar cold

The low temperatures, accompanied at times by fierce winds and drifting snow, not to mention the darkness and twilight "during the day" posed great challenges for the members of the research team, but after a period of acclimatisation, they worked together with determination and good humour. Standing still under the night sky while on polar bear watch and physical movement while setting up and operating the measuring instruments frequently alternated, making long working hours in the cold possible.

The low temperatures and snow drifts also put the measurement technology to the test. They challenged the team to break new ground even in comparatively simple activities. For example, a method had to be developed to anchor the guy ropes for the support structures of the fibre optic cables in the permafrost ground, which was literally as hard as ice, so that they could freeze into it. This was achieved with a battery-powered impact drill and pan head screws - along with a splash of hot water from the thermos flask. To fix the 1.2 millimetre fibre optic cabling within its only 0.3 millimetre thick stainless steel sheath, cocktail sticks made of bamboo and the wheels of a pedal trolley wrapped in foam rubber were used. The heat-conducting paste between the solid copper blocks of the reference baths turned out to be an indestructible bond at minus 30 degrees Celsius that could only be removed after thawing in the laboratory.

Fortunately, the grazing herds of reindeer found ways to avoid the network of fibre optic cables measuring about 300 by 300 metres, and not a single animal got its antlers or legs caught in the cables. Supports knocked over by reindeer could be set up again without damage or loss of data. In terms of these aspects of uncertainty, too, NYTEFOX was a true success.

New insights into heat transport

The evaluation of the measurement data is not expected to be completed until autumn 2021. However, it has already brought to light a multitude of previously undiscovered phenomena in the Arctic boundary layer which contribute to polar weather

Fig. 6: : The properties of the Earth's surface are constantly changing due to storms and snow drift, so the measurement setup has to be checked frequently. At least one person always keeps polar bear watch (Photo: Christoph Thomas).

Fig. 7: Inserting ground anchors for the support structures of the fibre optic cables in the hard permafrost soil was a special challenge. Overcoming the uncertainties associated with using this unique new measurement technology in the extreme Arctic conditions was one goal of the field experiment (Photo: Christoph Thomas).

Fig. 8: Installing the fibre optic cables, which are only 1.3 millimetres thick, at air temperatures of around minus 30 degrees Celsius required skill, stamina, and good gloves. In the background: the torch-beam of the polar bear guard (Photo: Christoph Thomas).

and climate patterns. Especially when the wind is weak and the sky is clear, the local mountains covered by glaciers are a source of cold air droplets sliding down the slopes, accelerated by gravity, into the valleys and further towards the fjord. These slow-flowing cold air currents of a few decimetres in thickness are directed or dammed on their way by small irregularities in the snow-covered surface – be it by earth banks, flat stream banks or the embankment of the former coal conveyor railway. They lead to strong temperature differences of up to ten degrees over a small area.

These differences, together with the air movement, can increase or suppress heat transport for a short time. They can therefore couple or uncouple the Earth's surface from the air. Conventional methods are unable to measure these influences, which result from the dynamic interaction of topography and surface. This fine-scale heat transport leads to the fact that even identical measurement methods deliver very different and seemingly contradictory results within a few hundred metres. These discrepancies stand in the way of comparison between modelling and observation. They also make it difficult to apply mathematical approaches such as those normally used in weather and climate models to calculate heat and energy transport.

These discrepancies had been previously noted, but it was not until the NYTEFOX field experiment that an empirically based explanation was possible. With the help of optical fibre technology, individual gravity waves, so-called solitons, were also documented. These move independently of the wind flow and initially lift the air near the ground, which is up to eight degrees colder. Then, however, they briefly lead to increased turbulence and mixing as they glide back.

"The network of fibre optic cables built in the NYTEFOX project is the largest of its kind deployed in Arctic climate and weather research to date."

Conclusion

Future research will reveal how best to incorporate the knowledge gained in NYTEFOX into modern weather and climate models. One thing is already clear, however. The uncertainty that stands in the way of a complete understanding of the Arctic boundary layer and the Earth's climate system, which is closely linked to it, will continue to be an important driving force for joint polar research by the University of Bayreuth and the Alfred Wegener Institute in the future.

Fig. 9: Mounting the optical fibres (Photo: Christoph Thomas).

Aljoscha Zahn
Tobias Baumann
Stephan Tremmel
Frank Rieg

Designing safe technical systems

Calculations and simulation make uncertainty manageable

View inside the ship lift in Niederfinow, at the eastern end of the Oder-Havel Canal. In 2007, it was the first structure to be awarded the distinction "Historic Landmark of Civil Engineering in Germany" by the Federal Chamber of Engineers, and is the oldest ship lift still in operation in Germany (Photo: Steffen Zahn / wikimedia commons / CC-BY-2.0).

The development of technical systems is a process that is continuously accompanied by uncertainty. Uncertainties already arise during planning, when the requirements for a new product as well as deadlines and a cost framework are examined. This continues during conceptualisation, which is particularly oriented towards the functions of the product to be realised, and in the subsequent design phase, which is concerned with the basic design of the product. In each of these development stages, the experts responsible for the design are faced with the challenge of identifying the sources of uncertainties and minimising, ideally even eliminating, them through suitable solution strategies. This is where modern calculation and simulation methods play a key role.

One particular example: In 2015, a bridge under construction near Graz (Austria) collapsed onto the railway tracks below (Fig. 1). The cause was an inadequately designed auxiliary scaffold, which had the task of supporting the 800-tonne reinforced concrete element. When dimensioning the scaffold, only the concrete loads were taken into account, but not the higher load after prestressing of the bridge element. Presumably, vibrations caused by a passing train then led to the overloading of a scaffold pier. The collapse caused damage of around € 5 million, which could have been avoided with a stress-related design and better communication between those involved.[1]

■ *Fig. 1 (left): Collapse of a bridge in Graz in 2015: The damage amounted to around € 5 million (Foto: wikimedia commons / The Adriatic Working Party / CC-BY-SA-4.0).*

In general, uncertainty in the development of technical systems always occurs when parameters are not known or when the value of a parameter cannot be precisely defined. Sources of uncertainty are not only the forces of nature, such as winds, precipitation, or earthquakes, but also, for example, the quality of materials, manufacturing processes, or environmental influences such as corrosive media

■ *Fig. 2: Uncertainties in the development of technical products (Photo: ist).*

(Fig. 2). Indeed, calculations and simulations of technical systems do make it possible to gain information about stressability and inherent safety. But new uncertainties also arise from the calculation itself, for example when doubts arise about the correctness of the selected calculation model or the correct interpretation of the results. In these cases, a whole range of established methods are available for design engineers to take account of the different sources of uncertainty.

"The finite element method can today be used in almost all technical areas for the analysis of relevant system variables."

■ The failure of a component is often caused by mechanical stresses (tension/compression, bending, torsion, or shear), which can lead to buckling, plastic deformation, forced rupture, or fatigue rupture. The tolerable load or failure limit depends on the material used. In order to increase safety from component failure, a so-called safety factor is integrated into the calculation. This factor is used to set the failure limit specified by the material for a component higher than would be necessary. An example: For a component, it is calculated that the failure limit must not be below 200 N/mm^2. If a corresponding material with this failure limit (for example the yield point or yield strength) is selected, a safety factor of 1 is given. A material with a limit at 400 N/mm^2 already offers twice that safety.

■ Uncertainties concerning, for example, the degree of stress on a component during operation can be reduced using mathematical formulations from the field of probability theory.

■ It is also important to know what influence an uncertain variable such as the temperature or the load assumption has on the system under considera-

tion. A sensitivity analysis can be used to determine how sensitively a calculation result reacts to changes in various input variables.[2]

The proper application of proven standards, as documented in norms or internal company guidelines, also makes it possible to reduce uncertainties in the development process.[3]

Fig. 3: Rules and regulations, which contribute to the safety of technical systems by prescribing norms or standards, contain, for example, estimates of maximum wind speeds, as they should be taken into account in the design of wind turbines with regard to the expected wind load (Photo: photography-wildlife-de / ist).

Cost, energy and resource efficiency

In addition to the goals related to the operational safety and reliability of a technical system or component, specified cost goals must also be achieved in the design process.[4] Certainty-creating iterations in the development process between design, calculation, and testing often have to be reduced for cost reasons. At the same time, the number of variants included in development typically grows at this point. Constantly increasing performance requirements and the desire to use energy and resources as efficiently as possible create a need for optimisation of existing products or require completely new technical solutions. Uncertainties can arise in this context, which must also be reduced.

Findings from material sciences lead to improved or new materials. Innovative technologies such as additive manufacturing allow a much more flexible design of components (Fig. 4). As a result, products can be developed that make optimal use of the available design space and are also lighter, more thermally stressable, or more chemically resistant. However, new materials and new manufacturing processes harbour great uncertainty due to lack of experience in working with them.

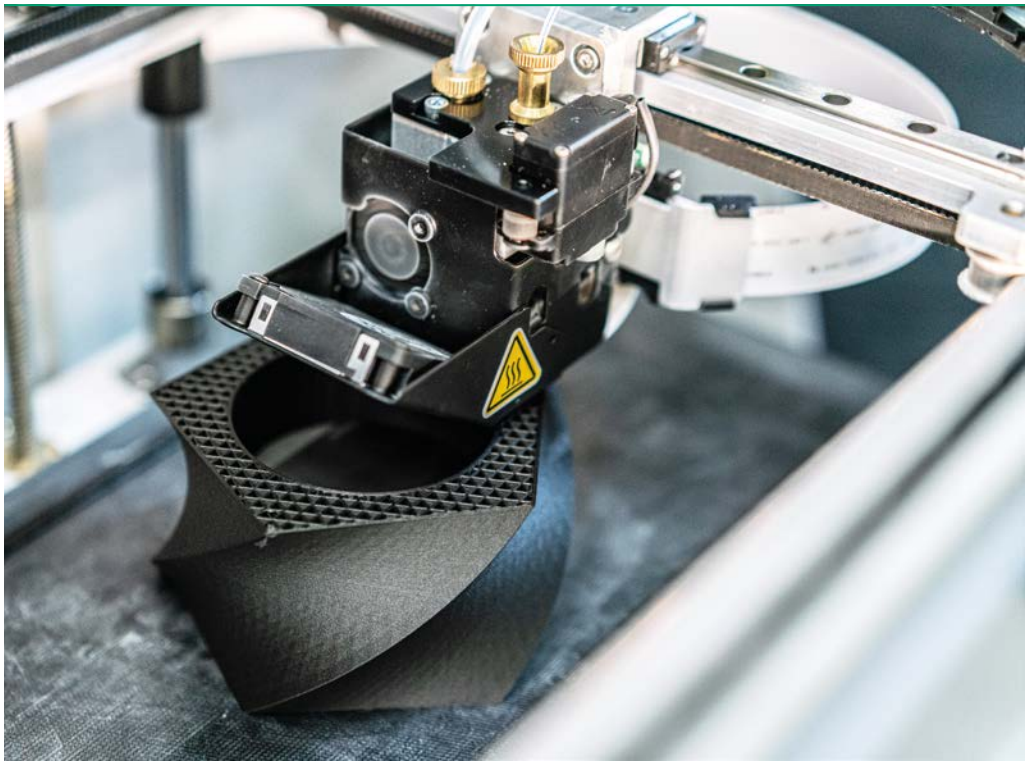
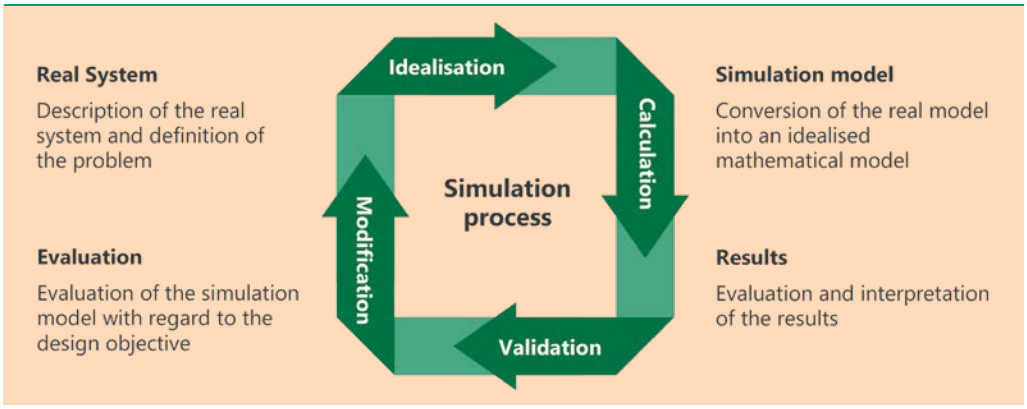


Fig. 4: The enormous flexibility of additive manufacturing opens up new possibilities in product development – and at the same time brings new uncertainties that need to be managed (Photo: Aljoscha Zahn).



■ *Fig. 5: Simulation process, based on Jonathan Smith: Quality Management in Engineering Simulation* [2] *(Graphic: Aljoscha Zahn).*

■ *Fig. 6: Simulation with finite element analysis using the example of a gear wheel – deformation due to a line load in the tooth mesh. The color scale red-green-blue highlights the deformation from the largest (red) to the smallest (blue) value (Image: Aljoscha Zahn).*

■ *Fig. 7 (below): Aljoscha Zahn M.Sc. calculates the deformability of a gear under load (Photo: Christian Wißler).*

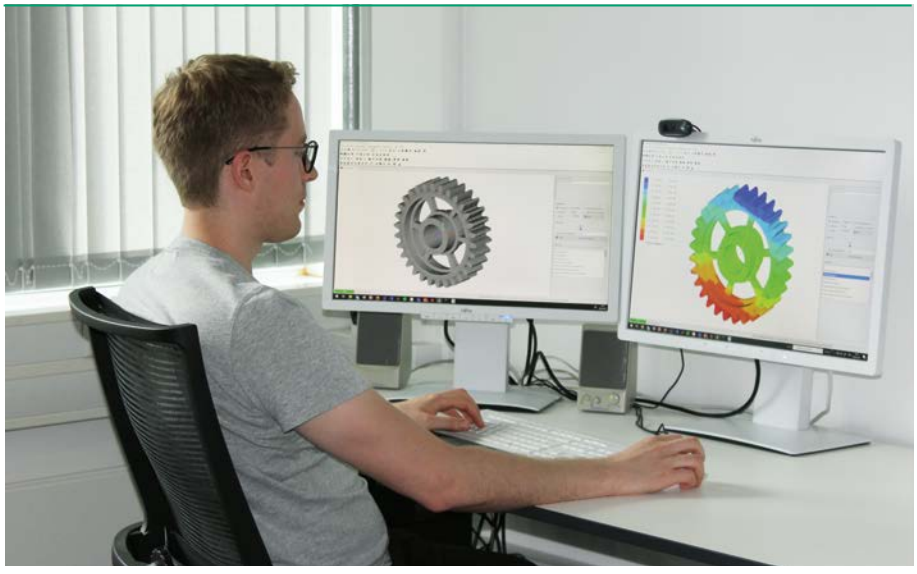
Safety through simulation

Reliable simulation of operating behaviour is therefore essential for the development of innovative and cost-effective products that also meet high safety standards. The course of a simulation is usually an iterative process (Fig. 5). In the preparatory phase, it is important to describe the problem and systematically identify all suitable calculation models and procedures in finding a solution. In the subsequent modelling phase, the problem is idealised in the form of a mathematical description and also digitised if computer-aided methods are used. On the basis of the calculation model, a solution must then be generated using a suitable procedure.

Many problems and interdependencies can be resolved very precisely by analytical methods. An example is the lowering of a steel beam at a load application point. However, if the demands on the depth of detail of the modelling increase and at the same time different boundary conditions – such as the behaviour of contact points or anisotropy of the material – have to be taken into account, analytical descriptions are often no longer possible. In this case, numerical calculation methods are preferable as they are particularly suitable for solving complex interactions.

Certainty through finite element analysis

Finite element analysis has established itself as the tool for analysing problems from a wide range of physical disciplines.[5] The underlying finite element method is a numerical procedure for solving differential equations with which most technical systems can be adequately described. For this purpose, the component under consideration is divided into a group of finite elements. How each individual element deforms under load can be described mathematically. From this, the behaviour of the component and – if the contact states are also taken into account – the behaviour of entire systems can be determined. In the case of a structural-mechanical calculation, the focus is on the deformation behaviour of the component and critical stresses (Fig. 6).



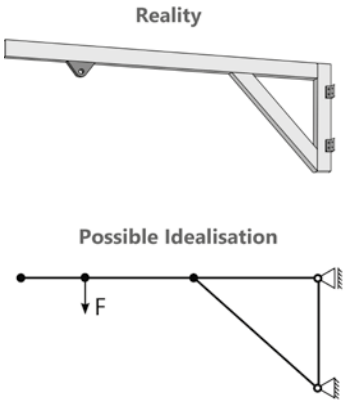


Fig. 8: A cantilever (left) and a possible idealisation for the calculation (right) (Graphic: Aljoscha Zahn).

Fig. 9 (right): Construction work in front of the Berlin TV tower (Foto: ArminStautBerlin / ist).

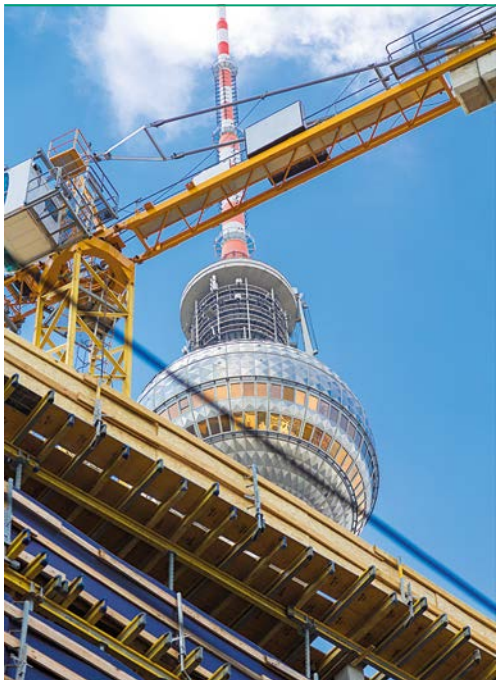
In other cases, the question is how the component reacts to dynamic excitations or how the temperature is distributed as a result of an imposed heat flow. Here, too, finite element analysis leads to precise, reliable calculations.

Hardware-related limitations and the associated restrictions in modelling have been successively reduced since the 1980s with the introduction of microprocessors and a general increase in the performance of modern computers. At the same time, the finite element method itself is undergoing constant further development. Consequently, it can today be used in almost all technical areas for the analysis of relevant system variables. In addition, advances in the field of computer graphics and the software development based on them promote the development of user-friendly programmes that have greatly simplified the visualisation of results and their interpretation in particular. As an analysis tool, finite element analysis fits optimally into the process of virtual continuous product development – and iterations in development are increasingly automated in the process.

Uncertainty in simulation

As much as simulations contribute to reducing uncertainty during the development of technical systems, the use of numerical calculation methods itself introduces new uncertainties into the development process. Inevitably, numerically induced rounding and truncation errors arise. These information losses can already falsify the input variables of the model. The idealisation of the problem in the form of a mathematical model, which is at the beginning of the modelling process, is also associated with a loss of information. There is no single way to describe a real component or system; rather, different models can always be derived (Fig. 8). One modelling option can be considered superior to another if it better fulfils its purpose. For example, one model has the advantage over another in better representing the real behaviour of a system. However, if this property is accompanied by exorbitant costs in computational time, the chosen idealisation does not fulfil its purpose. Ultimately, it is always a matter of finding a compromise between accuracy and computational efficiency.

The discretisation of the chosen mathematical description is another source of error in modelling. In the context of finite element analysis, it is particularly relevant in meshing, the subdivision of the component into elements. Here, element sizes must be chosen sufficiently "fine" to obtain a representative description of the geometry (Fig.10). This can be ensured by convergence analyses or adaptive methods.



RECOMMENDED READING

F. Rieg, R. Hackenschmidt, B. Alber-Laukant: Finite Element Analysis for Engineers – Basics and Practical Applications with Z88Aurora. Munich 2014.

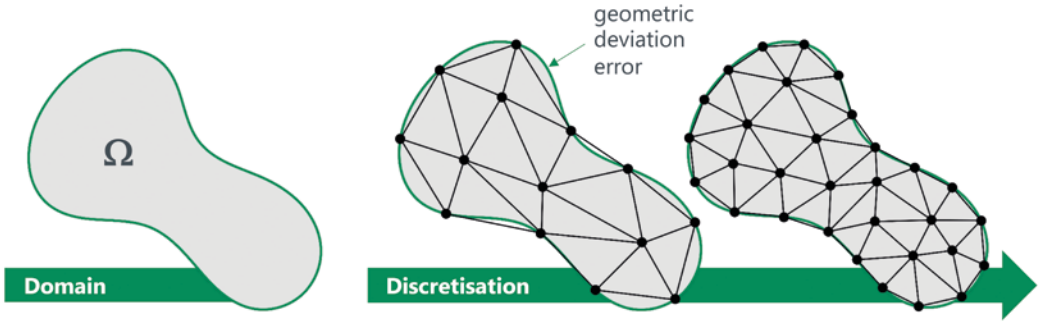


Fig. 10: Discretisation of an domain (left) using the example of triangulation. A sufficiently fine mesh size must be selected to map the geometry as accurately as possible (Graphic: Aljoscha Zahn).

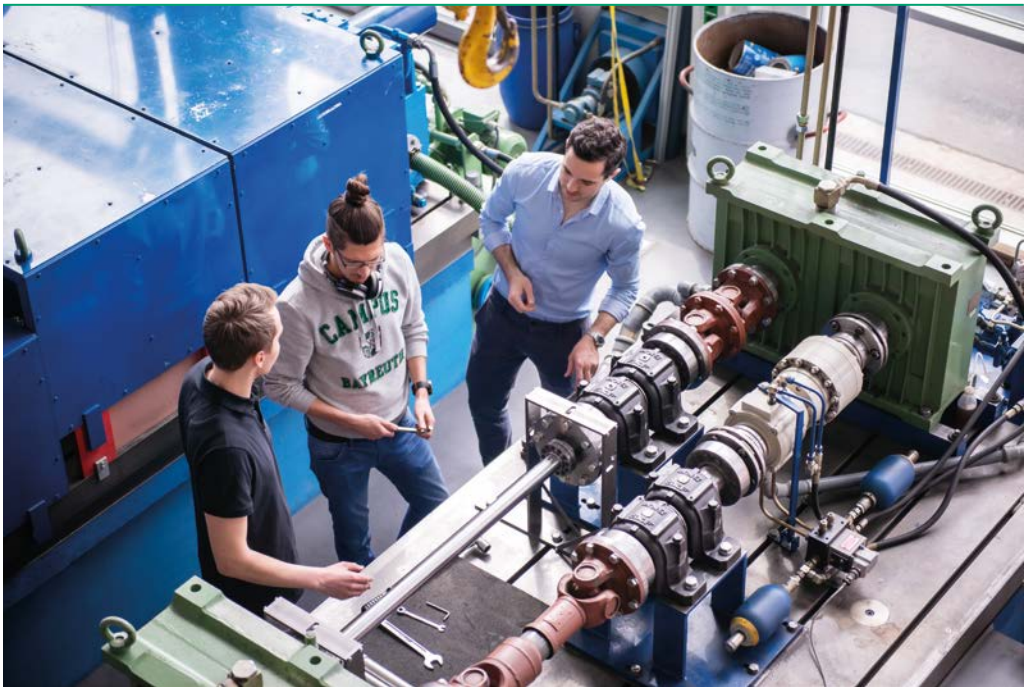


Fig. 11: Test hall at the Engineering Design & CAD research group at the University of Bayreuth. A member of staff and student assistants prepare a stress test rig for an overload test of a clutch (Photo: Engineering Design & CAD research group).

The greatest uncertainty, however, still comes from humans themselves. Modern applications do clearly simplify the simulation process and prepare the results in clear graphics. However, it is all too easy to place false trust in supposedly correct results. It is therefore the responsibility of the calculation engineer to identify the uncertainties of the chosen calculation method and to estimate the errors that may result from them. Then it is necessary to prevent these errors by taking appropriate measures.[6] Expertise and experience in the respective problem area are absolutely necessary for this.

Every simulation requires validation

In principle, modern applications for product design enable a completely virtual development process. However, the mathematical models used still have to pass the practical test. Validation against prescribed evaluation criteria and testing of real product behaviour are indispensable (Fig. 11). In particular, the use of additive manufacturing technologies can help to reduce the costs of model and prototype production ever further. In addition to testing load limits and analysing the service life of components and assemblies, key technologies of Industry 4.0 open up entirely new potential for the maintenance of technical systems.[7] For example, research is currently being conducted on sensor-integrated machine elements. These are designed to generate measurement data and evaluate it in real time, in order to identify critical instances of stress or deteriorating operating characteristics. Unscheduled failures can thus be actively avoided.

In summary, it can be said that as a result of constant methodological and technological progress, uncertainty in development processes can be eliminated ever more reliably through calculation and simulation – provided that these complex and demanding procedures are applied by highly trained and experienced professionals.

AUTHORS

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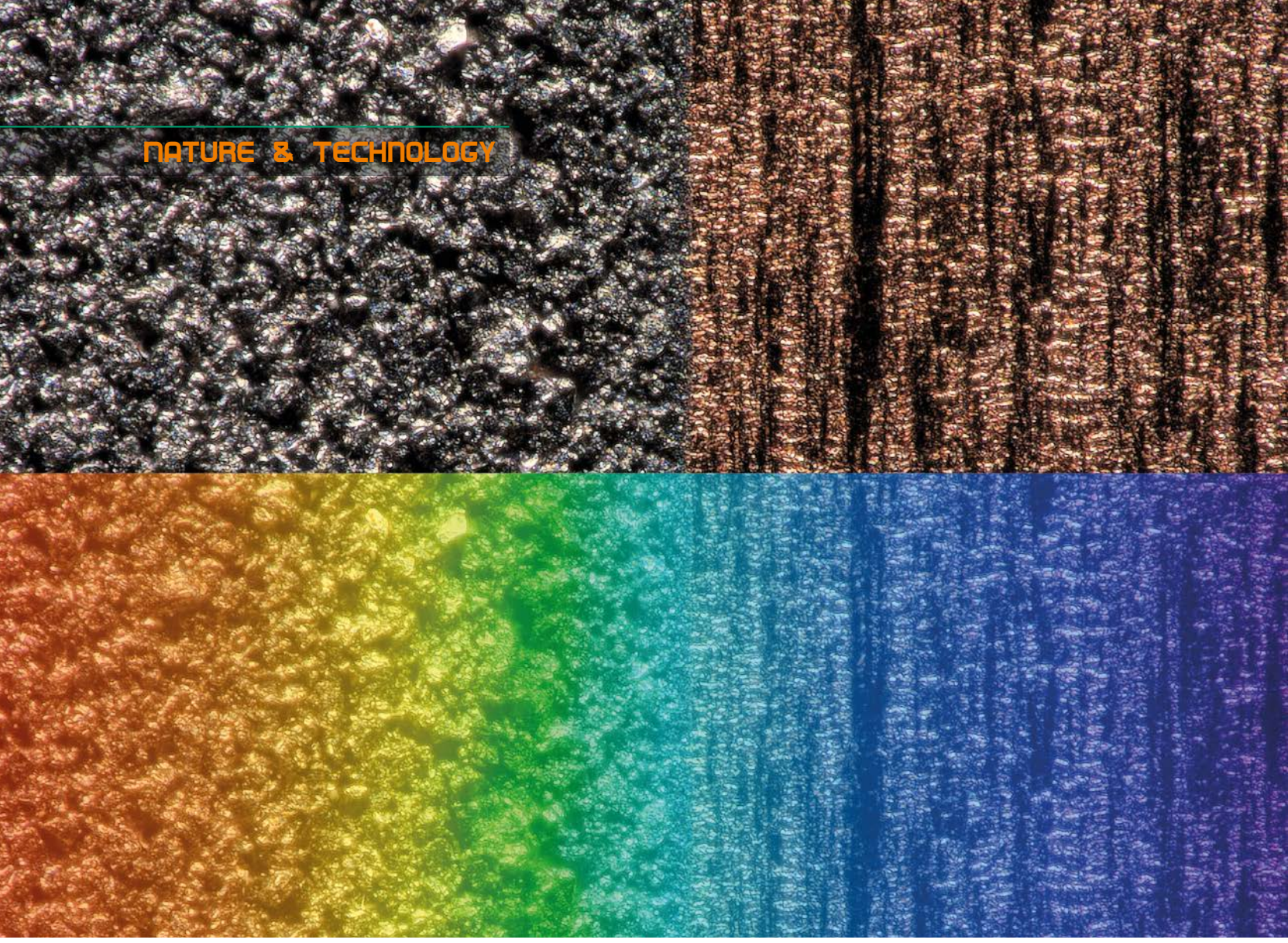
1 Industriemagazin: Fünf Jahre nach Brückeneinsturz in Frohnleiten: Prozess in Graz beginnt. https://industriemagazin.at/a/fuenf-jahre-nach-brueckeneinsturz-in-frohnleiten-prozess-in-graz-beginnt, status 11.06.2021.
2 J. M. Smith: Quality Management in Engineering Simulation; A Primer for NAFEMS QSS. Glasgow 2014.
3 VDI 2221 Blatt 1:2018-03 Entwicklung technischer Produkte und Systeme; Modell der Produktentwicklung. Berlin 2018.
4 K. Ehrlenspiel, A. Kiewert, A, U. Lindemann, A. Mörtl: Kostengünstig Entwickeln und Konstruieren; Kostenmanagement bei der integrierten Produktentwicklung, 8. Aufl. Wiesbaden 2020.
5 F. Rieg, R. Hackenschmidt, B. Alber-Laukant (2019), see recommended reading.
6 See n. 2.
7 J. Reichel, G. Müller, J. Haeffs (eds.): Betriebliche Instandhaltung. Heidelberg 2018.



Fridolin Röder

Uncertainty in battery systems

From their materials, to production, all the way to operation

Top left: Microscopic image of a battery electrode coated onto a current collector made of copper. Top right: the copper metal foil. The lower coloured section shows the height of the coating: Red areas are higher, blue areas are lower (Image: Fridolin Röder).

Battery technology is playing a key role in the switch to renewable energy and electromobility. Electric vehicles are no longer a niche product; battery electrodes and cells are being produced for just this purpose in "gigafactories". Meanwhile, the demands on the price and quality of these batteries are constantly increasing. Since production requires a lot of energy, the sustainability of electric vehicles depends on batteries having as long a service life as possible. This also includes a possible second phase of use, for example as storage for energy generated by photovoltaic systems in households. Determining the service life of a battery and – associated with this – assessing its sustainability is difficult and associated with considerable number of uncertainties. Other uncertainty in the context of batteries includes fluctuating product quality and uneven ageing of battery cells that go undetected.

Uncertainty

In a technical context, the term "uncertainty" describes the lack of certainty regarding a physical quantity or property. This uncertainty can result from missing or incorrect information. In any case, it can have a significant impact on the use of technical systems.

In mobile and portable applications, for example in electric vehicles and mobile phones, lithium-ion batteries are generally used today. In this type of battery, lithium ions are embedded in the positive and negative electrodes. The electrodes are made up of porous layers consisting of solid, mostly spherical particles. In a charged battery cell, the lithium is mainly in the negative electrode. During discharging, the lithium ions must move from the negative to the positive electrode. For this transport process, the lithium ions use the liquid electrolyte, which fills the gaps between the solid components in the battery. However, the transport through the electrolyte is associated with an unwanted resistance that reduces the performance of the battery cell. The shorter the distance to be covered and the more numerous and wider the transport paths are, the more this resistance is reduced. Therefore, the denser the particles, the greater is the resistance to the transport of the lithium ions and the greater is the resulting reduction in performance. However, especially with high particle density, a large number of lithium ions can be stored in the electrode, so that the storage density of the battery increases accordingly (Fig. 1). An optimal electrode design is therefore always a compromise between storage density and performance.

"A detailed statistical analysis enables better assessment of uncertainty."

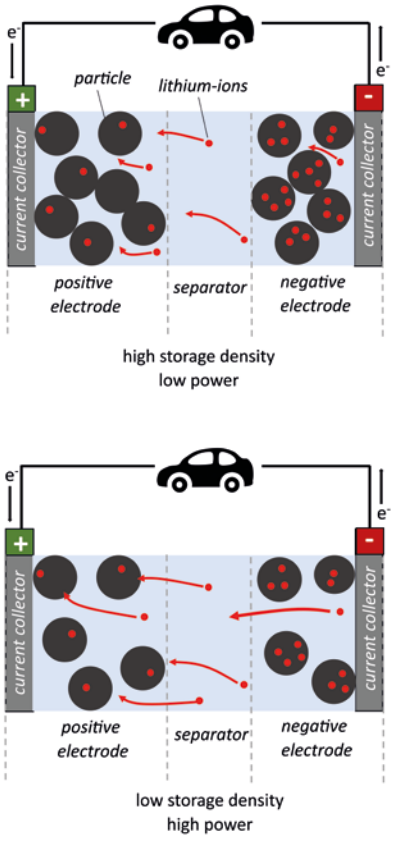
Even if battery cells have the same specification and were manufactured in the same production facilities, their electrodes may differ. The resulting differences between battery cells affect, for example, local current paths, energy density, battery cell lifetime, and safety. Large battery systems, such as those used in electric vehicles, consist of 100 to 200 individual cells. The battery cells in the system are all slightly different, with the weakest cell often limiting the performance and capacity of the battery system. It can even cause the failure of an entire battery array.

The differences between battery cells can become more pronounced during use. In this case, there may be a reduction in their lifetime and safety-critical failures of the battery system. To reduce these risks as much as possible, the differences between the battery cells must be well understood and estimated as accurately as possible when designing the system. In this way, they can be countered and minimized during operation by means of suitable battery management. On this basis, it is then also possible to ensure a long service life for the cells and a high level of safety for the system.

Manufacturing battery electrodes

Battery electrodes with specified properties are produced in a long chain of individual steps. Essential process steps are the application of the porous electrode coating to the current collector, and the drying and compaction of the electrodes (Fig. 2). There are machine-related variations in each of these individual steps, and there are also unavoidable minor differences in the starting materials used. This results in fluctuating properties of the electrodes, in particular

Fig. 1: The influence of electrode porosity on battery storage density and performance (Image: Fridolin Röder).



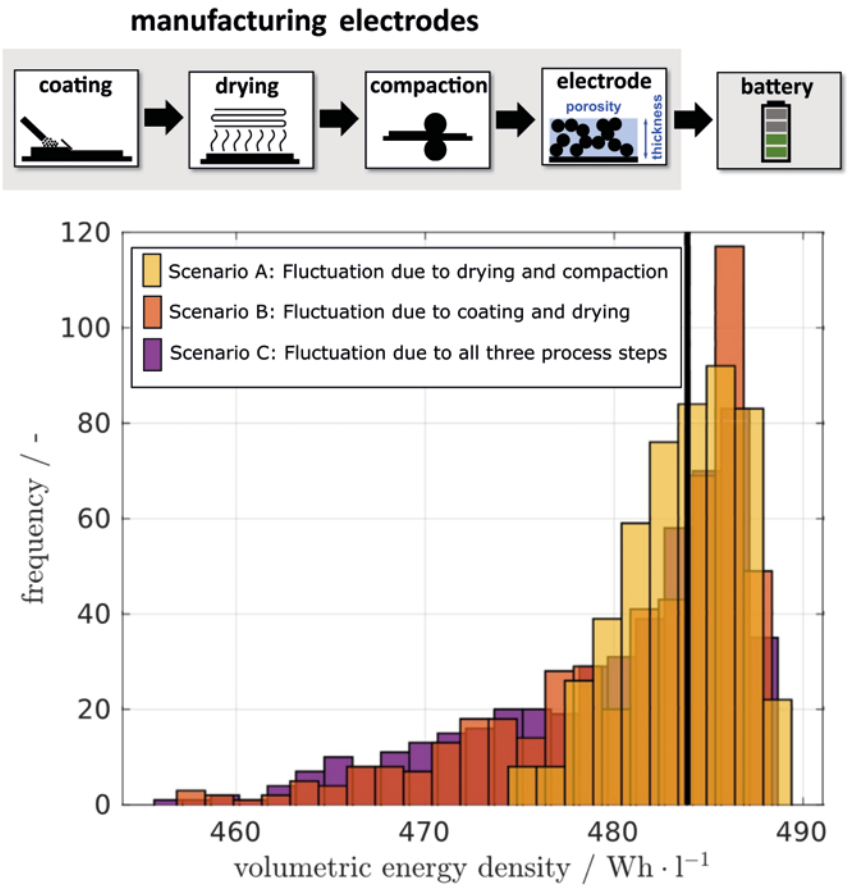


Fig. 2: Simulation study on fluctuations in electrode production and their influence on the energy density of battery cells. The graph represents the results of a statistical evaluation and shows the quality of virtually produced battery cells for three different production scenarios. Energy density functions as a quality criterion. It can be seen that fluctuations in drying and compression in scenario A have a comparatively small effect on energy density. In contrast, the fluctuations in coating in scenarios B and C have a considerable effect on energy density. Consequently, fluctuation should be reduced in the coating process step so that the product quality required remains unfulfilled in as few cases as possible, and rejects are minimised (Graph according to O. Schmidt et al., 2020)[1].

Fig. 3 (right): Specification and rejects in case of fluctuation in product quality (Graphic: Fridolin Röder).

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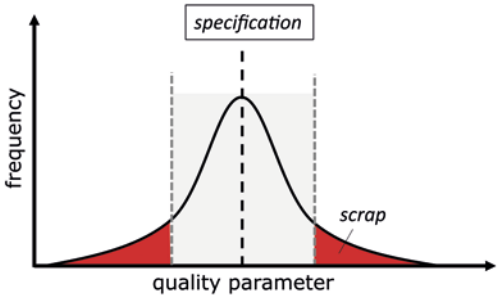
the porosity and thickness of their coatings are not always the same.[1] As a result, a consistent quality of the battery cells cannot be guaranteed. If the deviations are large, it is possible that some of the batteries produced will not meet the quality criteria to be fulfilled, and cannot contribute to value-adding as scrap (Fig. 3).

The causes of the uncertainties that arise in electrode production are manifold and often influence each other, making it difficult to consider them in isolation. Computer simulations can be used to investigate the manufacturing process and the influence of electrode properties.[2] This requires mathematical models for the individual production steps and the battery cell to be manufactured. Such models represent known cause-and-effect relationships in the steps of production and also processes in the finished battery by means of mathematical equations. Computer simulations have the advantage that various influencing factors can also be considered and examined in isolation, which is not possible in in a real plant. The model can also be used for a statistical analysis showing how fluctuations in the steps in production affect the inherent uncertainty of the battery cell (Fig. 2).

Operation of battery systems

When operating battery systems, the fluctuations shown can increase as a result of the ageing of individual battery cells. If battery cells differ in terms of their capacity and are connected in series in a battery system, different states of charge can result (Fig. 4). In this case, the cell with the smallest capacity limits the total capacity of the battery system and thus the range of the electric vehicle.

These differences must be compensated for by the battery management system, for example by taking measures to balance the charge. In order for the system to be able to do this, corresponding circuits, electrical components and controllers are necessary. However, these bring with them additional costs and



a reduction in the energy density of the entire battery system. When designing battery systems, battery management systems, and operating strategies, it is therefore important to know exactly how the cells differ from each other, and how their differences change during use. Typically, these differences increase during use. It is therefore necessary to determine the differences over the entire usage phase by means of stochastic analyses.

The varying degrees of battery cell wear during operation are often also due to the initial differences in electrode properties. For example, if battery

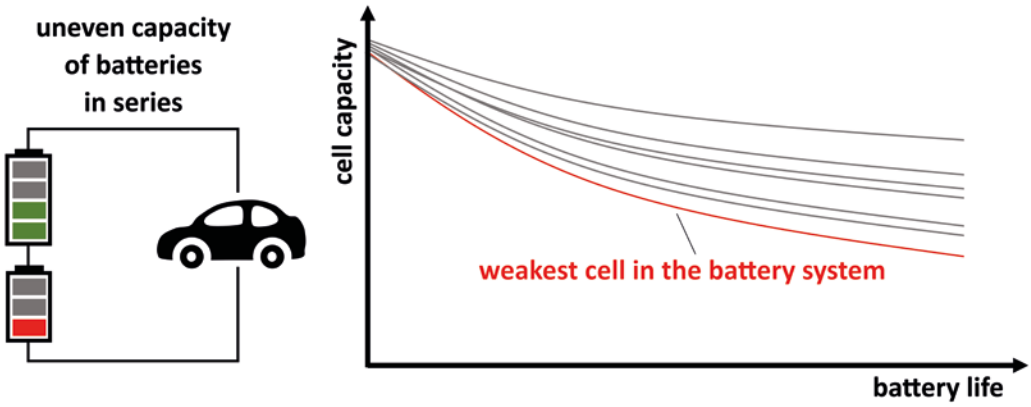


Fig. 4: Differences in capacity in interconnected battery cells (Graphic: Fridolin Röder).

electrodes have a comparatively high proportion of large particles, they can trigger undesirable processes, such as the deposition of metallic lithium (Fig. 5). Such side effects can be investigated in more detail using battery models that take particle size into account as a parameter with statistically distributed properties.[3] Corresponding computer simulations have shown that current densities at the surfaces of large particles are significantly higher, which can accelerate the degradation of battery electrodes. Battery electrodes should therefore have a particle size that is as uniform as possible in order to mitigate uneven ageing of the battery cell during operation.

Conclusion

Uncertainty in batteries can occur at a wide variety of levels - from the production facility to ageing processes at the particle surface. Computer simulations help to understand the causes. Based on suitable models, it is possible to predict and specifically reduce the differences resulting from the manufacturing process and ongoing operation. Furthermore, it has been shown that a detailed statistical analysis enables better assessment of uncertainty. Although this does not reduce the differences, measures can be taken in system design and operation that allow these sources of uncertainty to be dealt with appropriately. The combination of modelling, simulation, and statistical analysis is therefore a promising approach in the development of new battery systems. It stands to further the safety and reliability of technology in the field of electromobility.

RECOMMENDED READING

O. Schmidt et al.: Modeling the Impact of Manufacturing Uncertainties on Lithium-Ion Batteries. Journal of The Electrochemical Society (2020), Vol. 167, No. 6. DOI: 10.1149/1945-7111/ab798a.

F. Röder et al.: Simulating the Impact of Particle Size Distribution on the Performance of Graphite Electrodes in Lithium-Ion Batteries. Energy Technology (2016), Vol. 4, 1588-1597. DOI: 10.1002/ente.201600232.

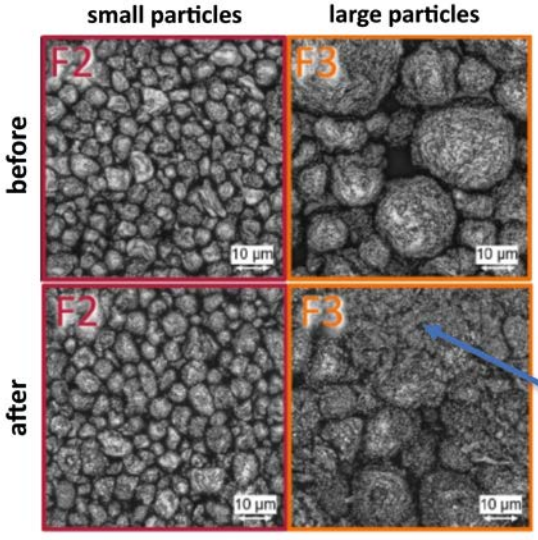


Fig. 5 (left): The microscopic images show the electrode before and after use. In the case of small particles (left), no change can be seen due to use. In contrast, lithium deposits are clearly visible on electrodes with large particles (right) (Image: Fridolin Röder. Microscopic images also used in L. Bläubaum et al., 2020).[3]

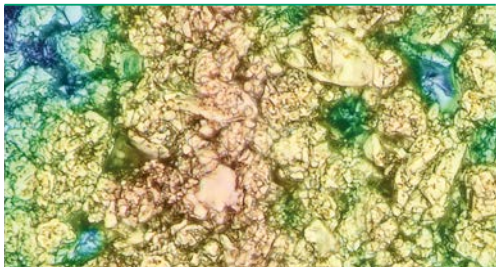


Fig. 6: The microscopic image shows how the particles are distributed in the coated battery electrode. The colour again indicates the height: Red areas are higher, blue areas lower (Image: Fridolin Röder).

1 Oke Schmidt et al. (2020), see recommended reading.
2 V. Laue et al.: Model-Based Uncertainty Quantification for the Product Properties of Lithium-Ion Batteries. Energy Technology (2020), Vol. 8, 1900201. DOI: 10.1002/ente.201900201.
3 L. Bläubaum et al.: Impact of Particle Size Distribution on Performance of Lithium-Ion Batteries. ChemElectroChem (2020), Vol. 7, 4755-4766. DOI: 10.1002/celc.202001249. – F. Röder (2016), see recommended reading.

Mirco Schönfeld

More data, less uncertainty?

Data models as the key to gaining knowledge

Large amounts of data alone are not enough to achieve certainty. The decisive factor is the modelling of the data, which depends on successful interpersonal communication processes (Photo: ist).

"Data is the most important raw material of our century." – "The world is one big data problem." – "Without Big Data, your company is like a blind, deaf deer on the highway." These and similar are the slogans of those who propagate the incontrovertible necessity of data analyses. In this way, they convey the impression that data analyses in turn produce incontrovertible certainties and, as it were, uncover a deeper truth from data. The impression is created that gaining knowledge is only a matter of the right algorithms and statistics. But is that really the case? In this article, we will look at the question of how knowledge can be gained from data. We take a look at how data is created and the context in which this happens. We see how data becomes models and why conscious data modelling is a necessary process. This finally gives us an idea of how useful knowledge can be gained from data.

Where is data collected?

First of all, we certainly think of the internet. While using the internet, we produce data: when we post something on social media, log on to a web portal to edit our emails, for example, or when we shop in an online shop. But we also produce data unnoticed, when we simply surf websites. Trackers are responsible for data collection of this kind. Trackers consist of programme code that is executed in the background when we visit a website in our browser. Trackers collect usage data and statistics: From which regions of the world do the website visitors come, at what times of day do they come and on which headlines do they click most often? This is valuable information for those responsible for a website. But even outside the internet and without a computer, we leave traces that are stored somewhere as data. Every EC or credit card transaction, every SMS, every phone call creates a "date". There are even dustbins that collect data.[1]

Why is data collected in the first place?

Since the new General Data Protection Regulation (GDPR) came into force, this question should be easy to answer. The GDPR defines the principle of data minimisation, which prohibits the unrestricted collection of data: Data may only be collected for a specific purpose. Since then, the data protection guidelines of the website, the house bank or the car-sharing service must transparently state what data is collected and for what purpose. These policies often state that data should help identify technical defects. Often, data is also used to improve products or services. This then conceals, for example, the intention to develop, train and optimise personalisation or recommendation systems. Under similar formulations, data is also collected to identify new business models and fields and to secure the economic sustainability of companies.

Generally, data is collected to minimise uncertainties – be they technical, economic or organisational. New insights are to be gained from data or predictions for the future are to be made. But is it that simple?

Big Data – and everything will be fine?

The buzzword "big data" is often associated with the promise that more data automatically means more knowledge and certainty. If only the amount of data were large enough, it would contain all the phenomena we need to teach our algorithms. After all, machine learning and artificial intelligence need lots and lots of data to train on. In reality, however, Big Data does not automatically reduce the uncertainties. If, for example, insights are to be gained about people and human behaviour, it is an important question whether collected data depict human behaviour at all. In an analogous way, this question is relevant for all areas of data-based knowledge gain - be it for internal market research and research for product improvement or for scientific research.

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Tracker as a key to gaining knowledge – about us as website visitors

One of the main functions of trackers is that we are recognised by different websites. This is done through so-called browser fingerprinting. Program code that is executed on web pages has access to certain properties of our computer and to settings that we have made on our computer via our web browser. This is not a security gap, but necessary so that a website can optimally adapt its display to the end device.

The mix of browser, operating system, and screen size often already narrow down the circle of known people very well. After all, the tracking software does not have to identify all the people in the world, but only reliably recognise those it knows. In most cases, individual persons clearly stand out from the crowd when the list of fonts installed on the operating system is consulted: After all, how likely is it that someone on the other side of the world has installed three selected fonts of the corporate identity of the University of Bayreuth? How clearly each individual differs from the mass of website visitors can be seen here:

https://amiunique.org/

But why can there be any uncertainty at all about the meaningfulness of the data? Let's take a look at data from social media platforms. Social media is seen as a gigantic source of data through which individuals and societies with their individual views and collective behaviour can be observed from behind a desk. However, what we observe and the data we can collect rarely contain a true reflection of human behaviour. This is because the mechanisms that control our attention or shape our social lives are also known to those who design and develop the social media platforms. These mechanisms are cleverly stimulated or subtly activated to increase the acceptance of a platform and to increase individual dwell time on the platform – and not to generate the most meaningful data possible about individuals and societies.

"A data model represents the real world as it appears in the further analysis process."

We must therefore always be critical of our data. We must question whether it really describes human behaviour or only reflects reactions to the stimuli presented on a website or social media platform. In this context, we also speak of the platform effect.[2] In addition to the platform effect, there are numerous other pitfalls that make a critical look at the existing data and the context in which it was collected indispensable. These include, for example, non-human data producers (bots), distortions regarding the representation of social groups, different norms and values of the users and much more.[3]

All too often, it is the context or purpose of data sets that is not sufficiently taken into account. This is especially the case with data that is not or not exclusively used where it is generated. This data embarks on a data journey: In the course of this journey, it is cleansed, standardised, reconfigured, linked to other data sets or aggregated at various stations. These operations increase the reusability of data sets or enable financial gains to be made from their dissemination. However, individual stations may each be subject to different political interests or socio-cultural values that justify different ways of handling data. In what a station passes on, the context and purpose of its input data are no longer recognisable.[4]

So a large amount of data alone does not help to create certainties. Rather, the context of the data collection and the intricate mechanisms associated with it are crucial. But how do we get to the knowledge that is supposed to lie dormant in our data?

From data to knowledge: a long way

Gaining knowledge from data naturally benefits greatly from knowledge of statistics, algorithms and programming. In scenarios where several parties are interested in the result of a data analysis, the algorithms are often not the most important thing. Such scenarios are found in science and business alike – for example, when the parties come from different scientific disciplines or from different departments of a company. In all these cases, the following applies: The central challenges in data-driven insight or decision-making processes exist at the interpersonal level. This is precisely where data modelling comes in. Data modelling is more than just selecting numbers and characters for data sets. Communicative negotiation processes form the core of modelling. These concern

- the importance of the data,
- the motivating question,
- the operationalisation of this question,
- the necessary components of the cognitive process chain.

Modelling the data starts with selecting the phenomena to be observed and deciding how to represent them as data. Will information be summarised and categorical placeholders stored? Will all properties of a phenomenon be stored, or will certain details be hidden? Are outliers recorded away from a norm? Often these questions are answered implicitly, without any awareness of the fact that data modelling is a very complex process. Yet the implicit answers already contain central modelling decisions through which a data model is constituted. A data model fulfils all the basic properties of models:[5]

- Models are always models of something, i.e. images of originals.
- Models usually contain only those properties of an original that appear to be relevant in model building.
- Models serve as placeholders of an original under defined conditions.

However, a data model has another important property: it represents the real world as it appears in the further analysis process. Thus it takes on a treacherous

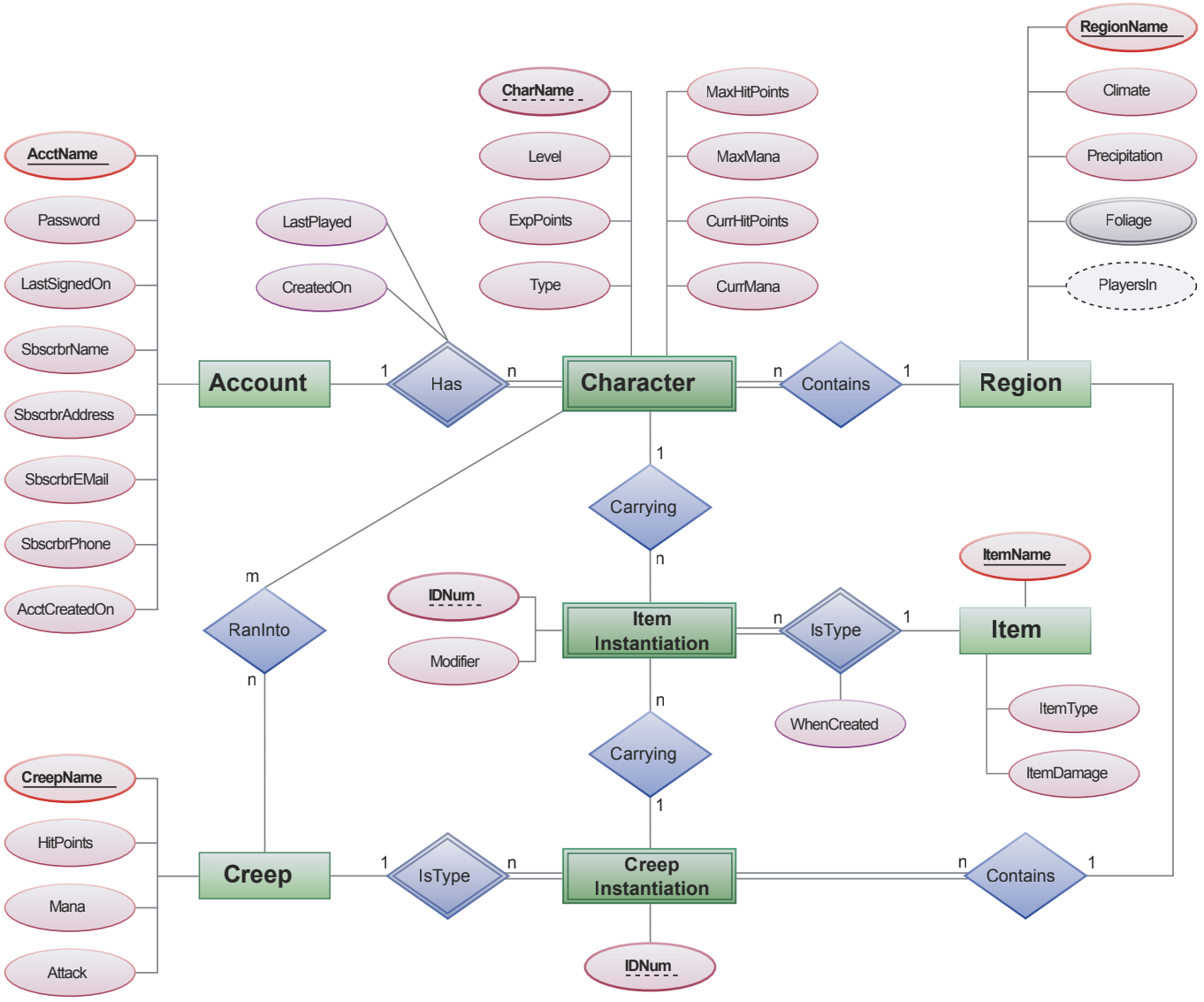

Fig. 1: Graphical representation of an entity-relationship model, as it is often used for the construction of a database. It represents objects and their relationships in a defined section of the real world (Graphic: Jorrit nl / wikimedia commons).

double role right at the beginning. Suddenly it no longer functions only as an image of an original, but also as a model for something new – in a sense for a new reality that comes after the data analysis. This double role is treacherous because modelling decisions at the beginning of the process chain, for example when observing and documenting the real world, have a considerable influence on the end of the chain and thus on the achievable quality of the data analysis. Thus, due to implicit, unconscious decisions made at the beginning of data modelling, potentials may be wasted that could benefit the gain of insight and knowledge in the later analysis of the data.

Negotiating the numerous modelling decisions in a goal-oriented cooperation is complex and challenging. It requires the willingness of all participants to engage in the thought constructs of modelling and the analytical evaluation of the data that is guided by them. Only when all participants have a clear understanding of what the data model represents and what it does not represent, only when all parts of the process chain are coordinated with each other, can knowledge be gained from the data from which everyone benefits.

1 Some trash cans collect data on their fill level and call the local waste management company when they need to be emptied: https://invidis.de/2018/11/signage-sunday- digitalisierung-fuer-die-tonne-iot-und- intelligente-muellei-mer/. Other examples record who disposes of which trash bags using facial recognition and QR codes on trash bags. Later, the system checks whether waste has been separated correctly: http://www.ecns.cn/news/society/2019-07-12/ detail-ifzkzyey4242240.shtml.

2 D. Ruths, J. Pfeffer: Social Media for Large Studies of Behavior. Science (2014), 346 (6213), 1063-4. DOI: 10.1126/science.346.6213.1063.
3 Ibid.
4 J. Bates, Y.-W. Lin, P. Goodale: Data Journeys: Capturing the Socio-Material Constitution of Data Objects and Flows. Big Data & Society (2016), 3 (2), DOI: 10.1177/2053951716654502.
5 H. Stachowiak: Allgemeine Modelltheorie. Wien - New York 1973.

Patricia Rich

At the mercy of uncertainty?

How we can make better decisions instead of bad ones

Signage on the Bahamas island of Stocking Island (photo: ist).

We make decisions constantly, but we are very often uncertain about some of the facts which are relevant to how our choices will turn out. For example, our leaders may be debating whether or when to allow beer gardens to re-open. This decision would be easier if they had a simple chart showing exactly what would happen given each possible opening date (as well as other relevant information); nobody has such a chart, however, so the decision must be made relative to their state of uncertainty.

There are two related questions here. First, how can I as a decision-maker make choices in these difficult situations? Second, if we observe someone else's choices, how can we evaluate them, accounting for the uncertainty that they face? Suppose that the beer gardens are opened on October 1st. What determines whether this choice was good or bad? On what grounds could we criticize the decision-makers for not allowing an earlier or later opening?

It seems clear that some decisions would be better than others; it's not an "anything goes" situation, despite the many factors and great uncertainty involved. Furthermore, we can't just wait and see whether we like the consequences of opening on October 1st, and praise or criticize the decision based on whether it turns out well. This would be easy, but unfair, because we would be basing our judgment on our newfound certainty about the consequences, which the decision-makers lacked at the time of choice.

Options for action and possible worlds

Both for the purpose of making and of evaluating decisions, philosophers and economists in particular will start by dividing choice problems into two components: facts and values:

- Facts are about how the world works, and when we face choices, facts about causal relationships and the consequences of our available actions are especially relevant. Unfortunately, we often lack many of the facts that bear on the problem at hand.

- Values reflect what we prefer, what we find good.

It's common to assume that we are not uncertain about our values themselves; this means that the primary challenge in decision situations is figuring out how to achieve an outcome that best realizes our values, given the uncertainty about the facts. For this reason the next, crucial step is characterizing the type and degree of uncertainty that we face. The focus here is on how we do this, so that we can respond appropriately to our state of uncertainty. In many cases the uncertainty will be formally represented, either qualitatively or quantitatively.

Arguably the most basic distinction we can draw is between knowledge and ignorance. A useful tool for representing and reasoning about knowledge and ignorance is the concept of "possible worlds." Our world is one of many possible worlds, but we are unable to say exactly which one is ours. Therefore, we reason about the set of possible worlds that could be ours, for all we know. We can rule out possible worlds that are incompatible with our knowledge. Many possibilities need not be considered in our decision-making process because we know they will not occur. We should ignore possible worlds in which opening the beer gardens triggers an alien invasion (although this is theoretically possible), causes the weather to improve, or fundamentally changes human psychology (such as how people respond to isolation, boredom or long hours of screen time) or biology (such as how the immune system responds to viruses).

We only consider possible worlds that reflect things we know to be true: We know a fair amount about relevant causal relationships, for example that sun and air circulation hinder the spread of viruses, that good weather and socialization improve people's subjective well-being, which in turn improves their immune functioning. We know that alcohol depresses immune function and that social contact spreads infections. We know something about the capacity of hospitals, the effectiveness of masks and vaccines, and the economic impacts of lockdowns and missed school.

So, the more we know, the smaller the set of possible worlds that we need to worry about. The difficulty is that we typically still have many possible worlds to consider. We may have knowledge of relevant basic causal relationships, all else being equal, but we are ignorant of exactly what will occur in our particular real-world context when all of these mechanisms (and more) combine. When two mechanisms pull in opposite directions, such as the health benefits of socialization and the adverse effect of infections, or the increased risk from social contact and the decreased risk from good weather, we are ignorant of what their combined effect will be, sometimes specifically and sometimes even very generally. We may have models providing estimates of combined

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effects in some cases; then, we have knowledge of what the models tell us, but we lack knowledge of exactly how the real-world effects may differ. This means that each of the remaining possibilities is a possible world that we cannot rule out. Importantly, we are also ignorant of what important factors we are ignorant of, and of what we think we know but are wrong about. This type of ignorance is especially hard to handle, but otherwise being clear about what we (think we) know and do not know gives us a good starting point for decision-making.

Numerical probabilities

The cataloging and categorization of knowns and unknowns – possible and impossible worlds – does not yet account for the fact that we may judge some possibilities to be more likely than others, among those we cannot rule out. A further tool for representing our uncertainty captures this feature of our decision problems: we can also rank possible worlds in terms of their likelihood, and often also quantify this likelihood. For example, we do not know how much protection a particular vaccine provides against new variants of a virus, but researchers are likely able to rank the possibilities according to their plausibility. We can imagine that a researcher considers it most likely that a given vaccine provides good but somewhat diminished protection against a particular variant, somewhat less likely that it provides undiminished protection, and less likely still that it provides severely diminished protection. We could make the list of alternatives more detailed and fine-grained.

"Being clear about what we (think we) know and do not know gives us a good starting point for decision-making."

A long tradition in philosophy and economics starts from the simple assumption that agents have comparative beliefs of this type, i.e. that individuals can rank alternatives in terms of their likelihood. This tradition goes on to show that under additional assumptions about the coherence of these comparative judgments, we (as theoreticians) can then assign probabilities to the options. This means that we could represent the researcher's beliefs about vaccine effectiveness by ascribing a probability

to each of the possibilities. We refer to uncertainty which can be quantified in this way as "risk," and it is especially convenient for decision-making purposes. For instance, it allows us to calculate the expected number of new infections, given our knowledge and beliefs. Combined with an assessment of how much we value any relevant outcomes of our available actions, there are theories that rank our available actions in terms of goodness. Probabilistic beliefs can also easily be fed into simulations used to anticipate the spread of the virus, and so forth.

The theory of risk that allows us to quantify our uncertainty by attaching precise probabilities to the possible worlds is both powerful and highly idealized. For some purposes, it is better to relax the theory in various ways; we do not always perceive our situation as one of simple risk, as if we were playing with dice. One important way of relaxing the theory is by attaching not precise probabilities to the possibilities, but ranges thereof. This often fits better with our intuitions and can be easier for the decision-maker.

For example, suppose that we ask an expert how likely it is that all willing members of the population will

RECOMMENDED READING

P. Rich: The key to the knowledge norm of action is ambiguity. Synthese (2021). DOI: 10.1007/s11229-021-03221-5

S. Grant, P. Rich, J. Stecher: Bayes and Hurwicz without Bernoulli." Journal of Economic Theory (2020). DOI: 10.1016/j.jet.2020.105027.

Fig. 1: The „Königliche Hirschgarten", one of the largest and most traditional beer gardens in Munich (Photo: zukanowa13 / istockphoto.com).

be fully vaccinated by a particular date. The expert may not be prepared to say that this is, say, 90 percent likely. Whether everyone is vaccinated may depend on other factors which are themselves uncertain; there may be many different possible worlds to consider. So the expert will not be confident enough to supply a specific probability on which we should base our decisions. They may, however, be willing and able to say something less specific. They may be able to provide worst-case and best-case probabilities, and so for example to judge that full vaccination by the specified date is between 60 and 90 percent likely. The uncertainty is therefore greater than if the expert had told us that it was 85 percent likely, but since we can still quantify the uncertainty, we are still in a good position to make decisions on its basis. Whether we orient ourselves according to the best-case, the worst-case, or attend to both is a question of values that needs to be determined by the relevant stake-holders. But clearly we are in a much better position to make good decisions given our values once we have gotten ourselves clear on the factual component to the decision. Again, there are many decision theories that can be applied to tell us what to do given this kind of uncertainty.

Even with the examples, this may all still seem quite theoretical and hard to put into practice. Actually, as we were writing a paper on this, my co-author remembered a wonderful historical illustration of how quantified uncertainty was critical to a high-stakes real-world decision problem. In brief, as scientists in the United States were doing research on atomic weapons and preparing to test the first atomic bomb, they discovered that they were uncertain whether testing the bomb would not in fact immediately obliterate the entire planet. In other words, they entertained possible worlds in which testing the weapon would instantly destroy all life, as well as others in which life would continue and the bomb would have various other impacts. The scientists could not determine the exact probability of earth-obliteration, since various calculations were involved, and the scientists disagreed. So, the situation was not a simple one of risk. The responsible decision-maker determined that they should proceed to test the bomb as long as the probability of earth-obliteration were no more than three in one million. Scientists were able to judge that to be the case, and we know how the rest of the story went.

Fig. 2 and 3: istockphoto.com.

David Stadelmann

Mobility in the pandemic

Risk preference controls behavioural adjustment

Before departing on the family holiday in summer 2020 (Photo: ist).

Humans adapt their behaviour to risks they are confronted with every day. In the course of evolution, this kind of adaptation has contributed not only to individual survival, but also to the survival of humankind. However, there are major differences between actual risks on the one hand and our perceptions and assessments of these risks on the other. In economics, the term risk preference has become established. Our risk preference is higher the more pronounced our willingness is to decide in a state of uncertainty on actions whose unintended consequences will only occur with a comparatively low probability. When, in everyday life, we have to decide in a short period of time on how to adapt our behaviour to given risks, our risk preference often carries more weight than the actual risk.

The risk preference of the population as a whole also play a significant role in dealing with the Covid 19 pandemic. This is shown by an empirical study published by the author of this SPEKTRUM article together with international research partners in November 2020. The study shows that at the beginning of the pandemic, in spring 2020, individual risk preference determined our behaviour in relation to the pandemic almost independently of government measures and actual health risks, which differed extremely according to age group. A better understanding of population risk preference allows us to see why behavioural adjustment after the first wave of the pandemic was different from that in subsequent waves. If parts of the population perceive Covid-19 as less and less threatening, this will affect behaviour and increase the cost of lockdown measures.

Costs, benefits, and risk preference

Risk preference is a fundamental component of human behaviour. It significantly determines our ability to navigate a complex, uncertain, and sometimes dangerous world. Normally, we weigh costs and benefits against each other. In daily life, we know the dangers and risks, we adapt to the environment or the environment adapts to us. This is how we have learned to stay safe. The thoughts that guide us in this are expressed in proverbs and sayings: "Better safe than sorry", and "Double is better." Being confronted with risks means having to make decisions in a state of uncertainty and assessing probabilities. However, as beings who think and act with limited rationality, we are not always good at this. A variety of factors influence our assessment of risk, and these assessments depend heavily on the context in each individual case.

Faced with great uncertainty, many people tend to focus on safety, meaning we do not conduct complex, comparative, and systematic risk assessment, but rather follow simple and proven rules that enable us to make decisions quickly. However, these rules are often imprecise and do not always lead to the best decisions (for us). For example, our assessment of risks in many cases depends on how far away we are from the source of the danger. However, such an approach works only to a limited extent with a virus like SARS-Cov-2, which is invisible and can even be transmitted by infected people without symptoms of illness. Risk is thus determined in the short term less by actual probabilities and more by our instinctive and intuitive reaction to danger. People who are naturally more willing to take risks have a greater risk preference. Not only are they willing to take more risks, but they often underestimate underlying dangers. On the other hand, risk-averse people see unknown risks as uncontrollable and often overestimate them. Moreover, our actions are always a function of context. Risk assessment is thus far from set in stone.

Voluntary restrictions on mobility

Looking back in history shows that massive restriction or regulation of mobility have been quite common, for example, in the Middle Ages. Funerals, the sale of clothing, and public gatherings were banned to combat the plague, and non-compliance severely punished. Generally speaking, states react to pandemics by introducing, expanding, or tightening controls. As the scale of the Covid 19 outbreak became apparent in spring 2020, many governments ordered measures aimed at increasing social distancing and

Fig. 1: Social distancing while shopping (Photo: ist).

RECOMMENDED READING

H. F. Chan, A. Skali, D. A. Savage, D. Stadelmann; B. Torgler: Risk attitudes and human mobility during the COVID-19 pandemic. Scientific Reports (2020), 10. DOI: 10.1038/s41598-020-76763-2.

"The extent to which people changed their mobility in response to the global pandemic depended crucially on how risk-averse or risk-tolerant they are."

Fig. 2: April 2021: Nordic walking in a cherry blossom park in Komono, Japan (Photo: petesphotography / istockphoto.com).

Fig. 3: Online conference in the home office (Photo: ist).

Fig. 4: October 2020: At Frankfurt Central Station (Photo: ollo / istockphoto.com).

isolation of infected individuals. Many citizens were also aware that the likelihood of infection increased when they went to public places and socialised with other people. Is it safe to shop, walk in the park, or use public transport? What is the risk of getting infected? How should we respond to the virus and the measures imposed? These were the questions many of us faced.

The study, published in November 2020, examines the relationship between risk preference and change in mobility during the first wave of Covid-19 in spring 2020, based on data from 776 regions in 33 countries. The focus is on the question of whether individual behavioural patterns in limiting social contacts can be explained by people's different risk preferences. The starting point of the study was the assumption that risk-averse people are more inclined to adapt their behaviour faced with the pandemic by restricting mobility and reducing social contact – and this independently of government-imposed restrictions. Risk-tolerant people, on the other hand, are less willing to change their mobility and thus their lifestyle. In other words, the hypothesis was that differences in behavioural adaptation are to a considerable extent due to different risk preference.

Mobility can be measured. In the new study, location data for public places was used for this purpose, which were divided into the categories of "retail and leisure", "supermarkets and pharmacies", "parks", "public transport", and "workplaces and residential areas". In the meantime, the collection and evaluation of such data has become a standard procedure in research. In spring 2020, however, this was not yet the case. At that time, at the beginning of the pandemic, the number of visits to public places was determined in two consecutive periods: first on all weekdays between 3 January and 6 February 2020, when Covid-19 was not yet perceived as an international threat, and then on all weekdays between 15 February and 19 May 2020. Visiting public places in the pandemic is not only an indicator of mobility and thus of a free lifestyle, but also of the risk of contracting the coronavirus.

Econometric analyses were used to investigate the influence of risk preference on the frequency of visits to these places. Preference was determined by Gallup World Poll using surveys. At the same time, the influence of demographic, geographical, and many other factors affecting the pandemic were also analysed. These factors included, for example, the timing of the classification of Covid-19 as a pandemic, the proportion of the population over 65 years of age, the incidence level of the disease, and, in particular, the numerous government measures, such as school closures, the cancellation of major events, and other lockdown measures. The analysis of these other influencing factors made it possible to specifically work out and measure the effect of risk preference on mobility – as independently as possible from those other factors that have a simultaneous effect.

Crucial: the expression of risk preference

Comparing the two periods, a decline in mobility was evident in almost every public place studied. This decline generally took place before the state-imposed lockdowns. In parallel, there was a significant increase in visits to parks, which were considered relatively safe environments.

The central finding of the study is that the extent to which people changed their mobility in response to the global pandemic depended crucially on how risk-averse or risk-tolerant they are. In regions where people are on average more risk-averse, they adapt their behaviour more to the pandemic, i.e. they reduce their mobility. Risk-tolerant people, on the other hand, react less strongly. A statistically strong and significant correlation between risk preference and change in mobility could be demonstrated in particular for visits to retail outlets and to sites of leisure activity. In regions with higher average risk tolerance, people were less likely to avoid these places during the pandemic.

The study also looked at how the official classification of Covid-19 as a pandemic affected mobility behaviour. It was declared by the World Health Organisation (WHO) on 11 March 2020 and thus preceded the lockdown measures of most governments. Behavioural changes had already begun to emerge. Social distancing and teleworking reduced mobility,

people avoided crowded train stations and restricted purchases to necessary goods. After Covid-19 was classified as a pandemic, this trend quickly intensified. All in all, the appeals to limit contact seem to have had a considerable effect – although the degree of this influence again depended on the expression of individual risk preference.

These results are supported by a comparison of Sundays with the rest of the weekdays. In "normal" times, most people work on weekdays and tend to pursue their hobbies and leisure activities at the weekend. With the onset of lockdown measures, visits to public places on all weekdays declined sharply. On the weekends, however, more (leisure) activity took place outside the home than during the week, as expected. Before the official classification as a pandemic, this trend was already clearly visible. However, the subsequent far-reaching infection control measures, which led to mass closures of shops and higher unemployment, caused mobility to decline at weekends as well, so that weekends differed less and less from workdays.

Voluntary restrictions and mortality risk

The study also addressed the relationship between mobility, risk preference, and the proportion of older people (65+) in the population. The analyses show that in regions where the proportion of older people is comparatively high, visits to supermarkets and pharmacies, the use of public transport, and commuting decreased more than in regions with fewer older people. There seems to be a similar correlation between mobility and the population share of older people in the retail and leisure and parks categories. The difference between risk-averse and risk-tolerant older people follows the general trend: people in regions with a higher risk tolerance rate the threat to their own safety and that of the general public lower than people with more pronounced risk aversion – even in regions with a larger share of older people in the population.

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Fig. 5: Digital proof of vaccination (Photo: ist).

Limited mobility in a country comparison

Global mobility in times of pandemic is the focus of a study published in *Globalisation and Health* in 2021. It looks at the question of how quickly and for what reasons the governments of various countries restricted international travel after first cases of SARS Cov-2 virus infection occurred in their respective jurisdictions. The study is based on the *KOF Globalisation Index*, which has been calculated annually by the KOF Swiss Economic Institute at ETH Zurich since 1970. The index expresses how far globalisation has progressed in political, economic, and social terms in more than 120 countries around the world. The study comes to the conclusion that countries with a high degree of globalisation did not react as quickly to first covid-19 infections as less globalised countries in restricting international travel. One reason for this could be that the first covid-19 infections occurred particularly early in highly globalised countries – with the consequence that governments did not yet have enough data to justify restrictions on international travel. It is also possible that the risks of infection and the speed of virus spread were underestimated in highly globalised countries.

Comparisons within the group of countries where globalisation is highly advanced are revealing. The more efficient the governance in these countries, the greater the time lag between the first infections detected and the imposition of restrictions on cross-border travel. This finding could be explained by the fact that health systems in less efficiently governed countries would be overwhelmed by a rapid increase in the number of infections – which is why governments might have been comparatively quick to take measures to reduce international mobility. In this context, the study also addresses the question of which aspects of globalisation cause the governments of heavily globalised countries to be rather reluctant to restrict travel. Their relative number of international treaties and memberships in international organisations were particularly important in this regard. Another important factor are the civil society and cultural exchange relations that a country maintains at the international level. Even more so than international economic relations, they prompt governments to refrain from significant interventions in cross-border mobility for the time being – even if a high number of infections have already been officially reported.

S. J. Bickley, H. F. Chan, A. Skali, D. Stadelmann, B. Torgler: How does globalization affect Covid-19 responses? Globalization and Health (2021), Vol. 17. DOI: 10.1186/S12992-021-00677-5.

Andrea Behrends

War, flight, displacement

Uncertainty in the border region between Chad and Sudan

The author in conversation with Cheikh Moussa (left) and Brahim (Photo: Inge Butter).

In her book "Questioning Misfortune", anthropologist Susan Reynolds White reports on her research in eastern Uganda.[1] She shows how people deal with uncertainty, and how it shapes their everyday lives in many ways. When a child falls ill, or the harvest is bad, or war breaks out, they face these often threatening situations with a pragmatic attitude. They do not strive for certainty, but for security. Like many other anthropologists, Whyte bases her work on the U.S. philosopher, psychologist, and educational reformer John Dewey. In his 1928 Gifford Lectures on "the pursuit of certainty",[2] Dewey argues that uncertainty is inherent in all learning processes in life. Without uncertainty, humans would not be able to settle into the world, understand it, or shape it creatively. We would passively accept the course of the world without being fully aware of our own ability to act.

Seen in this light, uncertainty, which goes hand in hand with a lack of clarity and predictability in individual life circumstances, is a necessary prerequisite for every human being to be able to actively engage with the world and independently find their own path in life. Social anthropologist Sandra Calkins also ties in with this understanding of uncertainty when she asks, well aware of the difficult challenges that people in Northern Sudan face every day: "Who knows what tomorrow will bring?" [3] Even when established ways of living together no longer apply and creative improvisation skills reach their limits – people still have to find ways to secure their own lives and those of their families out of a position of uncertainty.

The term "human security" originally comes from development research. The United Nations first used it in 1994 in its *United Nations Development Program (UNDP) Annual Report*. At that time, they were seeking to better align the planning of humanitarian, political, and military interventions with the real conditions as experienced by the people on the ground, and to promote a more realistic understanding of social processes to this end. In the social sciences, the concept of "human security" has proved fruitful, as shown, for example, by the research of anthropologist Thomas H. Eriksen.[4] While it is broad and quite vague, it provides a helpful point of reference for academic studies about social cohesion, integration, stability, and collective identity. Starting from the question of what offers people security or, conversely, increases their insecurity, their actions can be better understood – be it that they follow traditional patterns of behaviour and social rules, be it that they break these habits and replace them with new practices. The following contribution on the situation of people in the border region between Chad and Sudan, which is marked by war, flight, and displacement, also follows Eriksen's understanding of "human security". Four case studies will prove that it takes "hard work" to create "a secure life in a complex and turbulent world." [5]

From violent conflict to humanitarian disaster

When Chad began producing oil in 2003, the country started to become embroiled in the armed conflict in Sudan. The conflict in the western Sudanese region of Darfur, which borders eastern Chad, came to a head when Sudanese rebels launched an attack on a garrison of Sudanese government troops in February 2003. They were fighting for their inclusion in the then ongoing peace negotiations between the Sudanese government and the rebels in what is now South Sudan. The government's response to the attack on its troops in Darfur was swift and brutal: villages were burned, men, women, and children killed, and several hundred thousand people driven across the border into Chad in bombardments of the area and attacks by local militias against the unarmed rural population. This war, widely reported in the international media, was soon described as "the first genocide of the new millennium".[6] Since 2003, more than 280,000 refugees have crossed the border into Chad, and an estimated 180,000 people have been displaced within Sudan. At the height of the conflict, more than 100 national and international organisations were operating in the region under the auspices of UNHCR. As a result of continued insecurity on the Sudanese side of the border, more than 200,000 people are still living in UN camps on the Chadian side today.

The path to more stable conditions, which could provide more security for the people in this border region, is made difficult not least by structures of governance in Chad. Since the former French colony became independent in 1960, every change in the office of president has been the result of a military coup. Elections are democratic in name, but not transparent. The government under President Idriss Déby, which has been in power since 1990, has used the oil trade, among other things, to buy weapons

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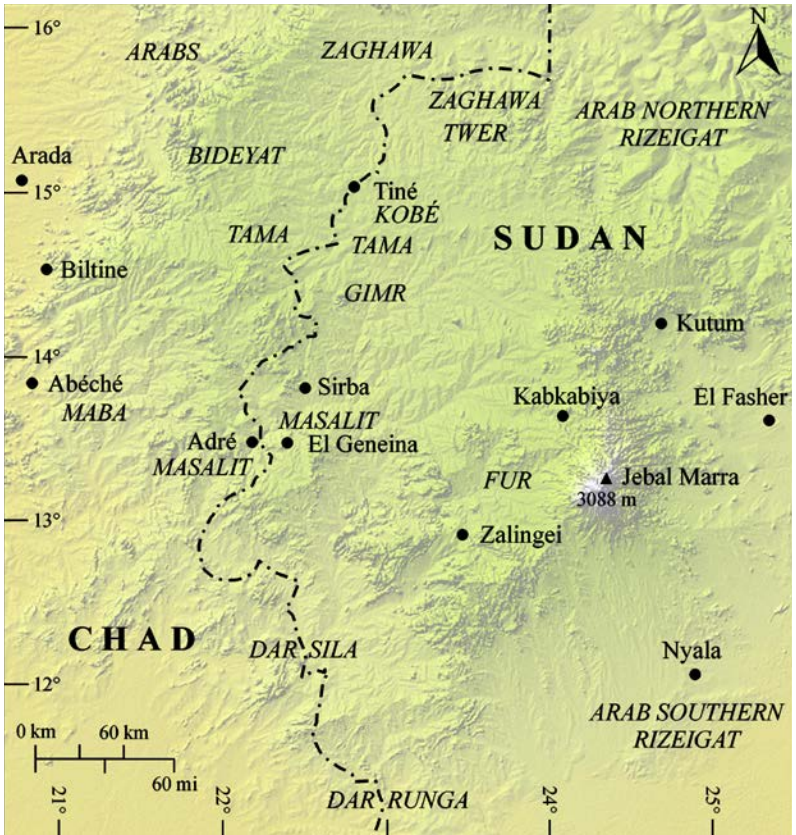

Fig. 1: The Border region of Chad and Sudan (Illustration: Jutta Turner / Andreas Gaube).

■ *Fig. 2 and 3: The UNHCR refugee camp in Farchana (Photo: Andrea Behrends).*

■ *Fig. 4: The market in Abéché (Photo: Andrea Behrends).*

with the country's revenues, to strengthen the loyalty of its own clientele through cash gifts and costly construction contracts, and to conclude contracts with the family of the state president and his closest supporters. On 19 April 2021, Déby was killed during a military intervention against a coup attempt in the north of the country. Since then, the country has been in a transitional phase. It is currently under the rule of the military, with one of Déby's sons ruling as interim president. The members of the presidential family enjoy extensive impunity and their behaviour often reinforces the widespread insecurity in the country.

Living in Uncertainty: Four anthropological case studies

The outbreak of war in 2003 led to many people on both sides of the border - both in the western Sudanese region of Darfur and in the villages near the border in eastern Chad – fleeing. They left their homes and land holdings to escape the escalating violence. The following is about the individual lives of four people I have met since 2001 during my fieldwork during the Darfur conflict: [7] Daldoum, Ashta, Moussa and Brahim. Their lives exemplify very different ways of dealing with the uncertain and threatening constellation created by the escalation of the conflict. Daldoum died four years ago, Ashta five years ago. Their pictures and their stories are published here with the express consent of their children and grandchildren.

■ When I returned to the Darfur border in 2007, I found the Chadian village of Hashaba, where I had lived six years earlier, almost completely depopulated. Only a few elderly people had remained there. They subsisted on wild berries they found in the bush. "In normal times this is the children's food," an old man told me, "and they eat it when they play in the bush. Now we have nothing else." I hardly recognised the old man they called Daldoum, whom I had met on previous visits as an active and lively man. He was very emaciated, his clothes were dirty and tattered. Daldoum had been the leader of the Sudanese refugees in Hashaba. A year ago, he said, all the others had gone to Adré, the largest town in the region with about 13,000 inhabitants, which is the last Chadian border post on the way to Darfur. The same happened in the villages around Hashaba. More than 10,000 people moved to the outskirts of Adré and lived there in straw huts, which were replaced after a while by more permanent houses made of wood or mud bricks and straw. They all felt threatened by the violence coming from across the border. If they had stayed, they feared that the rebels and militias from Sudan would have destroyed everything and killed them. And indeed, at the time of my visit in 2007, the militias came to the village almost every day. Daldoum told me that they sat under the biggest tree in the village and threw stones at them, shouting: "We will kill you and take your land" - but then they left the old people alone.

■ Daldoum's daughter Ashta also moved from Hashaba to Adré. On the outskirts of the city in "Hille Djidíde" - which means "New City" - she built a temporary hut for herself and her children. She earned a little money by working the land and by helping to make mud bricks. This enabled her to survive and even buy her twenty-year-old son a locally made horse-drawn carriage. By transporting people and goods, he now earned a little money himself, which he shared with his mother and young wife. Ashta said that if her parents stayed in Hashaba, the land-

■ *Fig. 5: Daldoum in front of the entrance to his house planted with millet (Photo: Andrea Behrends).*

holding there would hopefully remain with the family. She would visit her parents from time to time, walking a long stretch over the sand to bring them food and help with farming. When I last visited Ashta in 2011, she was still living in Hille Djidíde, while her parents had still not left Hashaba. A year later, international aid organisations replaced her hut with a house built of solid bricks. At the same time, other villagers who had moved to Adré began to temporarily return to Hashaba and farm the land around their former homes.

Cheikh Moussa also initially lived in a border village near Hashaba after fleeing Sudan. As a teacher and political activist, he found himself increasingly threatened as a result of the growing tension in Darfur. After minor attacks on his village and warnings from friends that he could become a target of state repression, he and the inhabitants of his village moved to Chad. Here, however, the local villagers, who had no ties to the newcomers' more distant home village in Sudan, denied them access to fertile farmland. Unlike Daldoum and Ashta, who had integrated into Hashaba, Moussa remained an outsider, viewed with suspicion by the villagers and also with envy because of his privileged access to international aid facilities. Therefore, he saw no other way than to leave the village together with the other Sudanese refugees and move to a UNHCR refugee camp. He chose the camp in Farchana because other people from Darfur had also sought safety there. In the camp, Moussa experienced great respect because of his education and previous social status, and he was elected spokesperson for more than 20,000 refugees. After his registration as a refugee and "vulnerable" elderly person, he was able to take advantage of various forms of support. But his living situation remains difficult to this day. On the one hand, Moussa told me, the refugees living in the Farchana camp cannot return to Sudan because of the ongoing high level of insecurity; on the other hand, they cannot integrate in Chad as long as they are denied access to farmland. The vegetable cultivation promoted by UNHCR and the income it generates is not enough to feed their families all year round.

Fig. 6: Ashta works in a farm labour cooperative comprising refugees only (Photo: Andrea Behrends).

Fig. 7: Ashta and her mother Hawaye in front of her parents' house in Hashaba (Photo: Andrea Behrends).

"Crucial to people's considerations were access to resources such as arable land, seeds and housing, as well as their respective individual forms of belonging to communities and places."

Moussa explained that there are three ways for the refugees living in the camp to make a living. They can trade goods from Sudan, work on the farms of the local population in Chad and sell the proceeds to Sudan, or they can take one of the paid jobs as a teacher, tailor, electrician, or construction worker in

Fig. 8: Moussa in the Farchana refugee camp (Photo: Andrea Behrends).

Fig. 9: Brahim at a hairdresser in the Farchana refugee camp (Photo: Andrea Behrends).

the camp. There are corresponding training opportunities in the camp, however, vacancies outside the camp are usually not filled by trained refugees, but by locals from the surrounding area. Moussa therefore still lacks proper prospects for the future – in contrast to Daldoum and Ashta, who have tried to maintain such prospects by living close to their land.

Brahim is from Chad and now lives near the UNHCR refugee camp in Hadjer Hadid. He and his relatives benefited from the presence of international organisations on the border with Sudan during the war. They were among the wealthier townspeople of Abéché and Adré, who had held a privileged position in the region long before the war. In Adré, Brahim had experienced war and its consequences from childhood. As a teenager, he had to abandon his education because his father, who had worked as a translator for the colonial administration, had died and his mother, a midwife, could not pay for the schooling of all her children. When in 2003 refugees arrived in Chad in large numbers, his eldest sister, who managed the UNHCR office in Farchana, helped him get a job with a Christian NGO that built shelters and market stalls in Farchana camp. This enabled him to afford to rent a house and invest in the construction of a larger house in Adré. In the years that followed, he achieved a certain level of prosperity, so that he was able to provide his family with some luxury goods – a motorbike, a satellite dish and a television, several mobile phones, a computer, and household items such as curtains, furniture, and kitchen utensils. The *displacement economy*[8] in the border area made this rise possible for him. However, when aid agencies began to withdraw from the border region with Sudan, Brahim lost his job. He first tried to make a living by buying a horse and helping farmers in the region plough their fields. With financial support from friends and family, he recently started a business making mud bricks. He sells them to young men who have found – very uncertain – work in the gold mines further north in Chad or across the border in Sudan. The few of them who return to their home region with a small fortune often invest in buying land and building houses.

Fig. 10: The trees in Wadi Shitété lose their leaves during the rainy season (Photo: Andrea Behrends).

In retrospect, the four different life and survival strategies proved to be at least partially successful. In the uncertainty caused by unpredictable political developments, people's actions are primarily determined by the question of what could be particularly precious in terms of their own survival and what they could save under the given circumstances. Decisive for their considerations were access to resources such as arable land, seeds and housing, as well as the respective individual forms of belonging to communities and places. For many, farming was a means of partially regaining a self-determined life and escaping dependence on the help and care provided in the camp. Some also managed to benefit from the general insecurity in the region, as Brahim's example shows. But his economic security was called into question as soon as the international aid agencies withdrew from the region. Of all things, when the war-related insecurity diminished, he found himself in a similar situation to the refugees he had previously provided shelter for. He too suddenly had to rely on his own manual and economic know-how as well as on financial support from family members and friends.

Prospects

Can general recommendations for action for projects and initiatives in development cooperation or migration policy be derived from the life histories outlined? The examples show how intertwined individual fates are in highly uncertain circumstances. This suggests that political interventions in future might take greater account of the multitude of the stakeholders, as well as their different options for action. Moreover, the practice of international aid operations to leave state actors in the respective regions out of the equation seems to be no longer sustainable. If it is to succeed in making the living conditions of the people on the ground more secure and reliable, new pathways must be found. For example, it would make sense to link immediate humanitarian aid operations with the longer-term development of more permanent forms of school education, health care facilities, or pension funds. Then people would no longer have to "choose between arm and leg", as one of my interlocutors put it. To survive uncertain times, all one's "limbs" must be taken care of.

RECOMMENDED READING

A. Behrends: Die Verwandlung von sudanesischen Geflüchteten in tschadische Flüchtlingsbürger. Eine bürokratische Statuspassage. In: D. Dizdar et al. (eds.): Humandifferenzierung. Disziplinäre Perspektiven und empirische Sondierungen. Weilerswist 2021, 106-134.

A. Behrends: Renegotiating humanitarian governance: challenging invisibility in the Chad-Sudan borderlands. In: J. Bjarnesen, S. Turner (eds.): Invisibility in African Displacements: From Structural Marginalization to Strategies of Avoidance. New York 2020, 19-35.

A. Behrends: Securing livelihoods. Economic practice in the Darfur-Chad displacement arena. In: A. Hammar (ed.): Displacement Economies. Paradoxes of Crisis and Creativity in African Contexts. London – New York, 35-56.

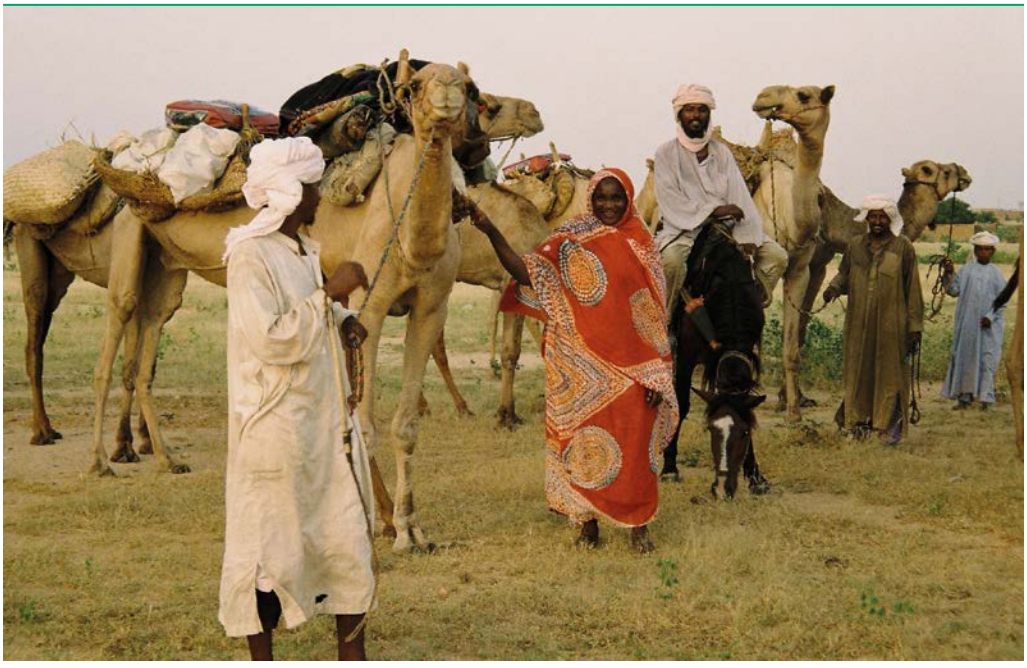

Fig. 11: Nomads taking a rest in Abéché (Photo: Andrea Behrends).

This article was translated from the German by Ralph Reindler.

1 S. R. Whyte: Questioning misfortune: the pragmatics of uncertainty in Eastern Uganda, Cambridge studies in medical anthropology. Cambridge – New York 1997.
2 J. Dewey: The quest for certainty. A study of the relation of knowledge and action. London 1929.
3 S. Calkins: Who knows tomorrow?: Uncertainty In North-Eastern Sudan. Oxford – New York 2013.
4 Cf. inter alia T. H. Eriksen et al.: A world of insecurity. Anthropological perspectives on human security. London - New York 2010.
5 Ibid., 5.
6 Cf. M. Mamdani: Saviors and survivors: Darfur, politics, and the war on terror. New York 2009 – G. Prunier: Darfur: the ambiguous genocide. Ithaca, NY 2005.
7 See recommended reading.
8 Cf. inter alia: A. Hammar (ed.): Displacement Economies in Africa. Paradoxes of Crisis and Creativity. London – New York 2014.

Stefan Ouma

Security and insecurity in the global economy

On the externalisation of costs and risk to the Global South

Photo left: Fruit and vegetable market in Kampala, Uganda; photo right: indoor market in Cannes, southern France (Photos: ist).

Uncertainty often also means insecurity. Insecurity and security are relative categories. They are subject to historical change and - depending on geographical and social circumstances - are experienced to a varying degree. What appears to be secure for one person is insecure/uncertain for another. Even in comparatively small-scale contexts, people who differ in their social status, for example, can be exposed to insecurity in unequal ways. For example, one person can expect a secure pension at the end of their working life, which will allow them to continue to enjoy a certain measure of material prosperity, while their neighbour, on the other hand, is threatened with poverty in old age.

However, insecurity and security are not only relative but also *relational* categories. As sociologist Stefan Lessenich has shown, the security derived from a certain level of prosperity, taken for granted in much of the Global North, is closely linked to the generation of insecurity for populations in the Global South.[1] Lessenich summarises this state of affairs with the term "externalisation". By this he means a way of life characterised by "the exploitation of foreign resources, the passing on of social and ecological costs to outsiders and the appropriation of profits internally, as well as the promotion of one's own advancement while impeding or preventing the progress of others."[2] His succinct conclusion is: "We live well because we live off others"[3] or, more precisely, live through the conditions of of others.

Insecurities in the agricultural sector: a global-relational perspective

The interdependence of security and insecurity in the global economy will be demonstrated in the following using the example of three economic geography projects. These research projects are based on the same observations and fundamental questions. How is it that food security, the guaranteed fulfilment of consumer wishes, and the expectation of profit margins and returns are realized in the Global North? And what are the consequences of this manufactured security for places and people in the Global South, where many commodity chains - especially for agricultural products - originate? Will there possibly be an increase in insecurity here? What are the consequences for small and medium-sized agricultural production enterprises as well as for agricultural communities and workers in the Global South if the Global North ensures that economic actors – whether in commodity or financial markets – have the most stable possible horizons of expectation and can count on their fulfilment?

Fig. 1: Spinach harvest in a field in Kenya (Photo: ist).

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"Uncertainty" in economic geographic research

"At the Economic Geography research group at the University of Bayreuth, we deal with the question of how sustainable regional development – for example in the countries of East Africa – can succeed in the face of global challenges. The focus here is on increasing socio-spatial inequality worldwide, the looming climate crisis and the advancing marketisation and technologisation of central areas of the economy and society. For more than a decade, I have been working on networked structures, institutions, and processes that have very different, often even contradictory effects in the Global South and the Global North. One focus was initially global commodity chains, later also global investment chains in the agricultural sector. Using the example of our own research projects, this article will show that the security of investors, companies, and consumers in globally networked relationships in one region is often associated with new uncertainties and insecurities in other parts of the world. Indeed, the terms "security" and "insecurity" are relative and relational.

This finding of social science research is reflected in the everyday experience of many people today - and not only in economic terms. Racialized discrimination and violence also mean that security and insecurity can be distributed very differently even in a small area. Travelling and excursions, which for white and German-speaking people are usually not associated with major physical insecurities, can be a journey into the unknown for People of Colour in some regions of Germany. I myself, for example, am very reluctant to give academic lectures in eastern Germany, given the many documented racist attacks there – it is simply too unsafe for me. At the same time, it should be remembered that there are also many People of Colour in the East who are living their lives under these circumstances, as well as politically committed people working to improve these conditions.

■ *Fig. 2: EurepGAP/GlobalGAP Certificate (2007) (Photo: Stefan Ouma).*

Safety standards for food

In 1997, European retailers belonging to the Euro-Retailer Produce Working Group (EUREP) launched a standard for food safety called "EurepGAP". As more and more companies outside Europe adopted this standard over the ensuing years, the name was changed to "GlobalGAP" in 2007. GlobalGAP now is a global organisation whose members voluntarily commit to complying with the standard. Its standard covers all stages of food production, from unprocessed agricultural products to further processing. Rules are formulated for fruit and vegetables, seeds and seedlings, livestock and aquaculture, as well as for the traceability of production and supply chains, all of which are intended to ensure the safety of food. In particular, contaminants are to be avoided or, if required, to be reduced. Companies can have compliance with these rules checked and certified by audit companies, which are accredited by GlobalGAP. In any case, the implementation of the GlobalGAP standard is associated with far-reaching consequences for the organisation of a company, and it is ultimately confirmed via an audit process.

GlobalGAP is therefore an institution developed in the Global North: an action-guiding set of rules that is intended to reduce uncertainties among consumers and supermarkets regarding the contamination of fruit and vegetables. But at the other end of the value chain, these rules have led to new uncertainties, as research in Kenya shows.[4] In the Global North, supermarkets were able to buy the higher product quality at an unchanged price because they could delegate the costly certification process to other links in the value chain. At the same time, as GlobalGAP spread more rapidly around the world after 2007, it was increasingly uncertain for many Kenyan farmers whether they could continue to export their products to the EU, and who would pay for the costs of certification. In addition, it seemed questionable whether this investment would pay off in a market that was already characterised by strong producer price fluctuations. This created new costs and organisational uncertainties for producers in the Global South.

■ *Fig. 3: Pineapple fruit at a market in Accra, Ghanaa (Photo: ist).*

A new variety revolutionises the pineapple market

Another economic geography research project funded by the German Research Foundation (DFG) dealt with the export of fresh pineapples from Ghana to the EU. In the mid-2000s, the West African country was considered one of the emerging countries in the global pineapple trade. Cultivation was concentrated in a region north of the capital Accra, and was largely carried out by smallholders, who in turn sold to exporters (Fig. 4). Some exporters also owned their own farms. In both cases, exporters supplied importers in Europe, who in turn supplied retailers.

By 1996, the conditions of competition in the global pineapple market had changed significantly. This was triggered by Fresh Del Monte Produce, a US-based transnational producer, distributor and marketer of fresh fruits, vegetables, and other products. That year, the company launched a designer pineapple that some called arguably the most valuable new fruit product in the world: the *Gold Extra Sweet Pineapple*, often cryptically called MD2.

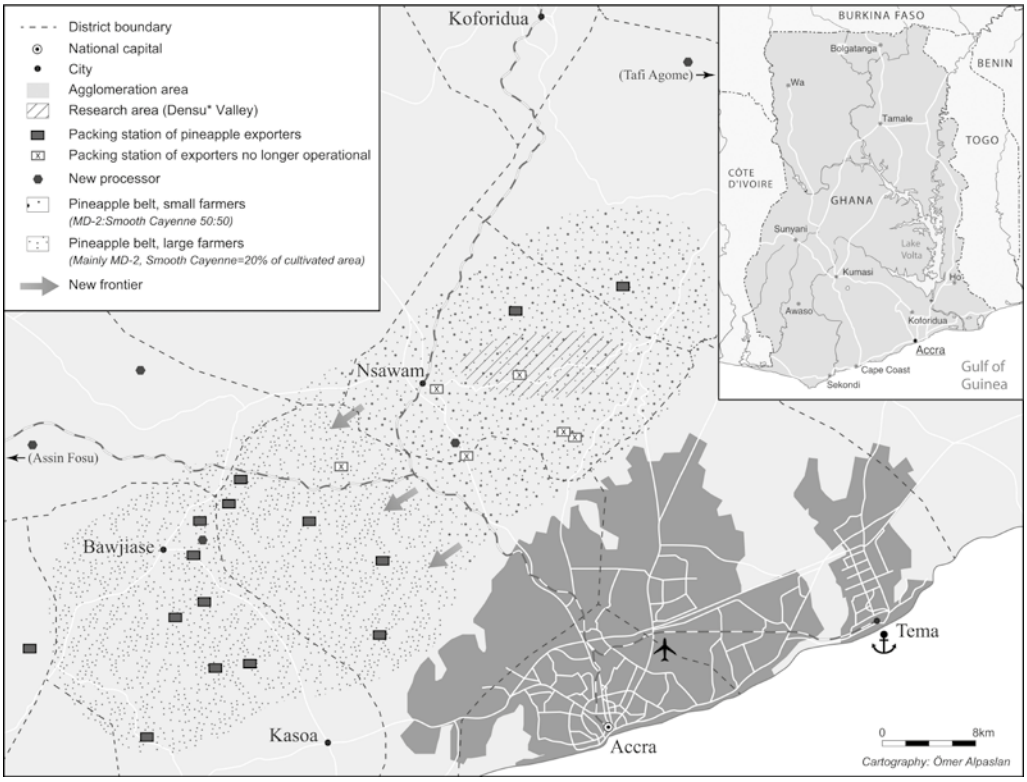


Fig. 4: Old and new cultivation areas in Ghana's pineapple belt (Source: Stefan Ouma 2020).

MD2 came from corporate labs in Hawaii and had been optimised for capital-intensive production on the flat plains of Costa Rica. The crop was intended to change the market to the agribusiness group's advantage and redefine the geographic scope of its sales markets. Until the mid-1990s, the world market was clearly sub-divided. Southeast Asian countries such as Thailand, the Philippines, and later Indonesia were the centres of pineapple cultivation for processing into juices and preserves, Central American exporters, especially Costa Rica, mainly supplied the US market with the Champaka variety while the European market for fresh pineapples was largely dominated by Côte d'Ivoire (Ivory Coast) and Ghana with the *Smooth Cayenne* variety. MD2 was promoted by Del Monte as having many advantages, notably longer shelf life, golden colour, and a sweet taste. The variety could also be easily transported by sea from Latin America to North America and Europe. This threatened the competitive advantage of Côte d'Ivoire and Ghana that had existed until then due to their proximity to Europe. Like many other transnational agribusinesses, Del Monte had considerable supply chain power and controlled the entire fruit chain, consisting of research, production, logistics and distribution, and ripening centres. For logistics, Del Monte was able to rely on its own refrigerated containers, specialised vessels, and freight forwarding companies.

MD2 can therefore be seen as the product of a strategy by which a company used the power potential of its vertical integration to secure more market share. The aim was to stabilise expectations and returns for investors, management, and employees. The sales argument was also to promise buyers more security with regard to the quality of the traded product – according to the motto "everything from a single source". For smallholders and exporters in Ghana, however, the flooding of the market with MD2 was an external shock that led to new insecurities. They were increasingly unable to sell their traditional pineapple varieties. In order to be able to convert their own production to MD2, it was necessary to learn the right way to handle the designer pineapple through a lengthy process of trial and error. Many exporters and farmers who could not afford to switch to MD2 dropped out of the pineapple business entirely. While there were between 50 and 70 exporters in the late 1990s and about 40 percent of the pineapples exported from Ghana were produced by smallholder farmers at that time, these numbers dropped drastically by 2009.

By 2011, only 14 exporters were still active in the market. Ghana's pineapple exports remained relatively constant only because the large-scale farmers who managed to convert to the new variety compensated for the loss of *Smooth Cayenne* exports. The surviving exporters spread their MD2 plantations to a new area west of Accra, where they opened up large tracts of land to an increasingly mechanised form of pineapple cultivation (Fig. 4). This in turn led to many migrant (non-autochthonous) smallholders with weak land rights losing access to land. Here too, people without ancestral land rights were suddenly

The Covid 19 Pandemic: Externalisation in Crisis

In the Global North, the Covid 19 crisis has had the effect of shattering previous - supposed - certainties. Massive economic downturns, the imminent collapse of health systems, curfews and radical eschewal are experiences that were previously more likely to occur in the Global South. At the same time, the pandemic has exacerbated the well-known systemic imbalance. In Germany, many people were saved from the worst economic consequences through short-time allowances and other transfer mechanisms. However, these instruments are by no means available to every state, nor would every state that was fiscally capable mobilise its resources in the same way. Moreover, Germany and some other states in the Global North have been able to develop their own vaccines.

However, the new securities generated in this way cannot be experienced globally. Broad-based access to COVID-19 vaccines is made more difficult or even prevented, among other reasons, because numerous countries of the North cling to patent protection, even though the TRIPS framework of the World Trade Organisation (WTO) provides for exceptions. On the other hand, it is already clear today that without such access, there will be no lasting protection against the SARS-Cov-2 coronavirus and its variants, even for the Global North. It appears that the mechanisms of externalisation described by sociologist Stefan Lessenich, which this SPEKTRUM article illustrates with examples from agriculture, have been called into question in their very foundations for the first time by this pandemic.

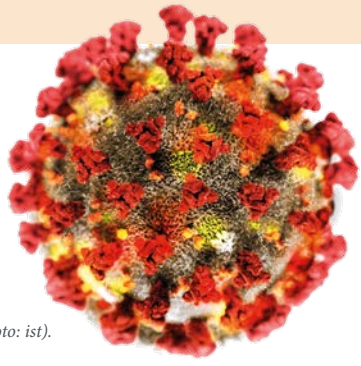


Fig. 5: 3D view of the corona virus (Photo: ist).

confronted with new insecurities as a result of the expansion of the MD2 cultivation area. [5]

Global investment in agricultural land

In a recent DFG-funded project, the Economic Geography research group at the University of Bayreuth investigated the influence of global investment chains on land markets in Tanzania and New Zealand.[6] Such chains are largely driven by asset managers, especially private equity firms, which invest money from endowments, pension funds, wealthy individuals, and other sources in agricultural land and associated farms (Fig. 6). In the wake of the 2007-2008 financial crisis, agriculture became a new asset class. Due to a rising global population and an interesting risk-return profile, farmland and agriculture were seen as a safe haven for investment. Financial players cleverly cultivated the narrative of land (agriculture) as a new alternative asset class and set out to institutionalise and professionalise it in order to reduce uncertainties for potential investors. For many investors, agriculture was by no means a self-evident safe investment, as one capital manager (asset manager) reported in 2014:

> *"You have to constantly explain and preach: Agriculture is a system with extremely many equations and even more unknowns. This means that many decisions are made under conditions of uncertainty. You can never capture all the factors 100 per cent. This is not industrial production. And you have a lot of volatility, not only in terms of prices that you might get away with, but also in terms of yields. And these compound on each other, which means the volatility of returns will be x times the volatility of prices. Investors need to understand that."*

The stabilisation of the new "agriculture" asset class via social, communicative, and institutional investments by the financial sector has ultimately caused more institutional investors to venture into agriculture. This connection can be clearly illustrated by the example of New Zealand, one of the global "hot spots" for private equity investments in land and farms.[7] Fig. 7 clearly shows how investments by institutional investors (summarized under "equity-driven investors") – for example pension funds – have increased since 2010. These investments target farms exclusively as an object of return.

The stabilisation of agriculture as an alternative asset class reflects the fact that the risks perceived by

RECOMMENDED READING

Parts of this SPEKTRUM-essay appeared in: S. Ouma: Waren, Wissen und „Raum": Die Dunklen Seiten globaler Lieferketten im Lebensmittelhandel, in: N. Baur et al. (eds.): Waren – Wissen – Raum. Interdependenz von Produktion, Markt und Konsum in Lebensmittelwarenketten. Wiesbaden 2020, 486-516.

Further studies:

T. J. Klinge: Foreign investments in New Zealand's agricultural sector and their regulation, 2001–2017. Globalizations (2020). DOI: 0.1080/14747731.2020.1795427.

S. Ouma: Agriculture as Financial Asset: Global Money and the Making of Institutional Landscapes. Newcastle 2020. Open Access: https://www.agendapub.com/books/95/farming-as-financial-asset .

A. Vorbrugg, S. Ouma: Transformationen des Ländlichen: Land und Landwirtschaft in der Globalen Marktgesellschaft, in: H. Gebhardt et al. (eds.): Geographie: Physische Geographie und Humangeographie. Berlin 2020, 905-91.

1 S. Lessenich (2017): Neben uns die Sintflut. Die Externalisierungsgesellschaft und ihr Preis. 4. Auflage, München – Berlin.
2 Ibid., 23-25.
3 Ibid. 24.
4 S. Ouma (2010): Global Standards, Local Realities: Private Agrifood Governance and the Restructuring of the Kenyan Horticulture Industry. Economic Geography 86 (2), 197-222.
5 C. B. Barrett et al.: Smallholder Participation in Contract Farming: Comparative Evidence from Five Countries. In: World Development (2012), 40 (4), 715-730. DOI: 10.1016/j.worlddev.2011.09.006.
6 S. Ouma (2020): Agriculture as Financial Asset, see Recommended Reading.
7 T. Klinge, S. Ouma (2019): Zur nationalen Regulierung globaler Agrarinvestitionen, see recommended reading.

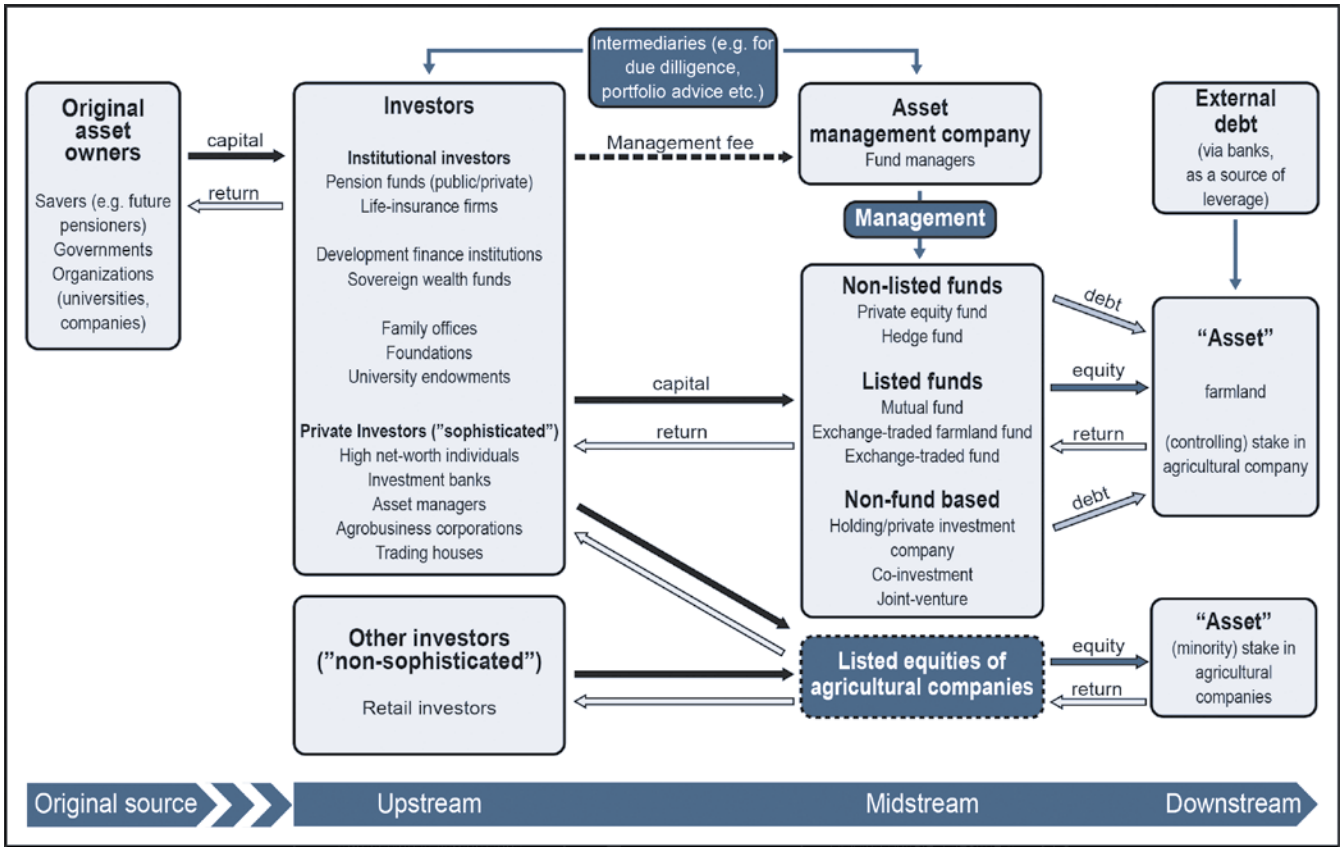


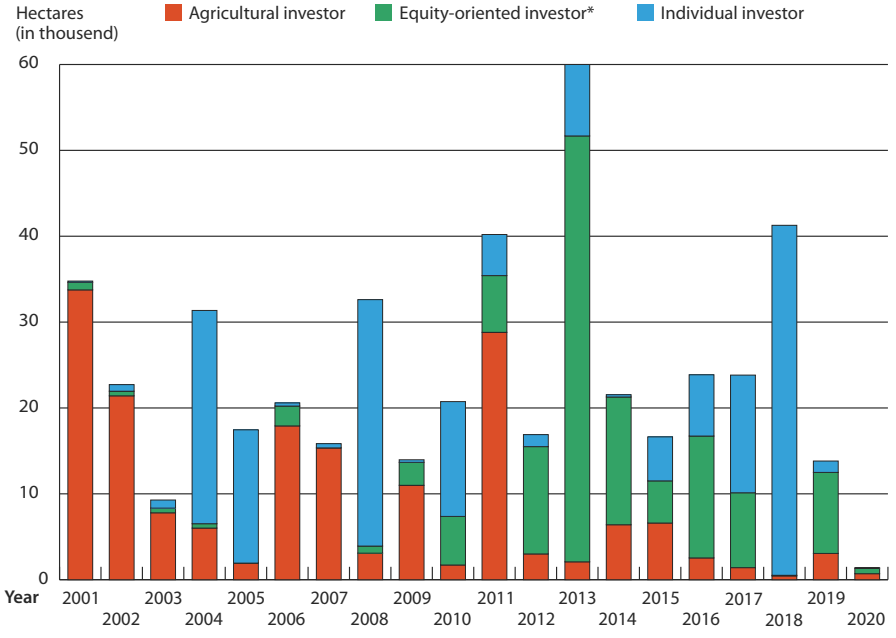
Fig. 6: Channels for investment in farmland and farms (Graphic: Stefan Ouma).

investors in this investment domain have decreased. On the one hand, this development releases new capital flows for investment. On the other hand, it often leads to new processes of concentration in land ownership and to price increases on land markets. For New Zealand, our research found that farmers who are already landowners benefit from this because it increases their capital value. For farmers who do not own land, on the other hand, this dynamic creates new uncertainties about access to and the price of agricultural land. Foreign investors cannot be held solely responsible for these developments, but they sometimes have a share in them.

Conclusion

These three examples from economic geography research show that the creation of security for certain groups in certain places in the global economy can be accompanied by the creation of insecurity for other groups in other places. Global supply and investment chains are the transmission belts for the spatial redistribution of security and insecurity. Therefore, they deserve special scholarly attention.

Fig. 7: Trends in farmland investment in New Zealand by investor type, 2001- 2020 (Source: Editing by Sebastian de la Serna, research group of Economic Geography, Univ. of Bayreuth, based on data from the Overseas Investment Office and CAFCA).



(n=1174) Observation year: 2021 *includes both investors oparting according to private and public equity principles

Alexander Brink
Frank Esselmann

Corporate Digital Responsibility

How communication about values secures trust in the digital transformation

Communication processes that focus on people's interests and points of view are increasingly proving to be a necessary prerequisite for reducing social insecurity in the face of increasing digitization and for building trust (Photo: ist).

The debate on responsibility in digitalisation, or Corporate Digital Responsibility (CDR) for short, is in full swing. Back in July 2016, the authors of this SPEKTRUM article presented a number of theses on the future of this topic.[1] The parallels in the development of corporate responsibility (CR) and CDR were crucial in this. In the following, the aim is to continue these reflections on CDR - in particular from the aspect of how companies can counter widespread uncertainty triggered by the digital transformation and its consequences. At the centre of these considerations are processes of communication, which should be well conceived and designed from both a scientific and ethical perspective.

In view of the highly dynamic development of digitalisation and the particular challenges inherent in its many ambivalences, the requirements for CDR formulated in 2016 have been confirmed. Companies should

- actively address the value conflicts around digitalisation and overcome conflicts between business and society within the framework of a shared value strategy,
- consider the entire value chain from a multi-stakeholder perspective to ensure its successful implementation, and
- successfully apply the tools proven in CR management to many CDR challenges.

During the pandemic, the relevance and urgency of the tasks arising from digitalisation for companies and society as a whole have become more acutely apparent. The lack of acceptance and use of digital tools such as tracing apps, some insufficiently regulated security aspects of homeschooling solutions, and ethical problems in the use of sensitive information to prioritise risk groups have exemplified how important transparency, trust, and the broadest possible consensus really are in the value issues revolving around digitalisation. The Hippocratic oath to do good and avoid evil requires the transition to a new, digital ethics of responsibility.

Value issues surrounding digitalisation set the agenda

The potential and dangers of digitalisation have contributed to a creeping uncertainty in society and strengthened mistrust. Hardly a day goes by without critical reports about cyberattacks, data loss, security breaches, deep fakes, or the misuse of artificial intelligence. On the other hand, however, processes of obtaining, analysing, exploiting, and disseminating data have become an integral part of most companies' business activities. They therefore feel compelled to take a public stance on their handling of data and on the possible dangers associated with digitalisation.

"Increasingly, ethics is proving to be a tool for dealing with uncertainty and insecurity."

Regulatory activities by policymakers already require companies to comply with high standards: the General Data Protection Regulation (May 2018), the Guideline of the High-Level Expert Group on Artificial Intelligence set up by the EU Commission (December 2018), the expert opinion of the Federal Government's Data Ethics Commission (October 2019), and, most recently, the EU Legal Framework for Artificial Intelligence of April 2021[2] – to name just a few examples. At Digital Summit 2019, the platform for exchange between policymakers and businesses sponsored by the Federal Ministry for Economic Affairs and Energy, European values were a dominant subject of discussion.[3] Business has responded to these challenges with numerous initiatives and projects, such as WG Ethics of "Initiative D21 – Network for the Digital Society", the Bertelsmann

Fig. 1: Screenshot of the website https://initiative-d21.de from 26.09.2021.

Foundation's "Ethics of Algorithms" project, the "Digital Networking Charter", and the "econsense Blueprint" for implementing digital responsibility in companies.

At the centre of all debates about the potential of digitalisation today – as already predicted in 2016 – is the compatibility of business and society, the shared value principle. Two initiatives, in particular, in which government and companies are working closely together on the topic of CDR are clear signs of how seriously the players take this common objective: on the one hand, the recently developed CDR Award under the patronage of three ministries of the Bavarian state government,[4] and on the other hand, the CDR initiative of the Federal Ministry of Justice and Consumer Protection.[5]

CDR Initiative of the Federal Ministry of Justice and Consumer Protection

Codes are written rules of conduct or voluntary commitments to which both institutions and individuals can commit themselves. In critical cases, they sound out various options for action. In this way, they reduce uncertainties and provide guidance for decision-makers in ambivalent situations. Principles are intended to provide orientation, and support companies in aligning their operational processes permanently and reliably with the requirements of CDR.

Prof. Dr. Dr. Alexander Brink, Professor of Business Ethics at the University of Bayreuth, and Dr. Frank Esselmann of concern GmbH provided scientific support for the development of these guidelines. An important starting point was value conflicts around digitalisation between business and society, which were addressed in the context of a shared value strategy. The entire value chain was considered from a multi-stakeholder perspective – focussing on politics, business, and science – with a focus on business-consumer relations (B2C). Last but not least, the proposal for a voluntary commitment and associated reporting has also found its way into the guidelines. These are tried and tested instruments of CR management, such as those used within the framework of the UN Global Compact.

https://cdr-initiative.de/kodex

CDR requires an integrative approach

The basis of digitalisation in companies is data collection and data storage, which runs through all phases of the value chain – right up to contact with consumers. For this reason, companies identified consideration of *the entire value chain* as an indispensable technical and ethical challenge in the first nationwide company survey on the topic of CDR.[6]

Attempts at more precise systematics can be found, for example, in the defined fields of action of the CDR initiative or in the Building Bloxx of the German Association for the Digital Economy.[7]

CR instruments are proving their worth – but there is still a need to catch up

An initial stocktaking shows that the problem identification tools developed in the field of CR can be transferred well to new challenges created by digitalisation. Based on established findings on CR, intensive work is being done on materiality analysis, risk classification, seals, reporting formats, codes, and the governance of innovation processes, especially with regard to CDR. As with CR, there are deficits in the area of impact measurement, which aims to record the effects of the respective instruments and measures as precisely as possible. In addition, the answers to some detailed questions are still in their infancy, for example binding definitions of terms (taxonomy) or the inclusion of CDR in remuneration and incentive models, and in the recruitment of employees. These issues are likely to become increasingly relevant in coming years.

What will the development of the next few years look like?

The prediction from 2016, that social currents and debates would significantly shape acceptance on the part of customers and consumers, has been confirmed in many respects. In a recent study, 70 percent of consumers state that they consider the assumption of responsibility on the part of companies to be very important or important; only 32 percent say that the handling of digitalisation by German companies is currently quite or very responsible.[8] In the further course of the study, there have also been insights into where consumers see the greatest need for action – namely in practical measures such as high data and security standards, direct contact with employees, and improved transparency in matters of contracts and data protection.

Against this backdrop, earlier considerations should be supplemented by a further thesis: *In navigating the uncertainties of digital transformation, companies need to focus more on consumers.*[9] A central challenge of the next few years will be to communicate problems, discussions, and, above all, solutions much more immediately to consumers. So far, this process

has often been conducted as a professional and technical dialogue between the specialists themselves. This way, however, too much potential for building trust and acceptance is left unused. In addition, companies receive too little support in the change processes required by the digital transformation, in which the perspective of customers and consumers is of fundamental importance.

Digitalisation – ambivalence and uncertainty are built in

Digital processes are inherently alien to humans to begin with. They are largely invisible and cannot be physically grasped, their binary logic is difficult to access, and there are no analogous processes in earlier human history. At the same time, however, digital processes have come to impinge on us most intimately today. They range from external stimuli emanating from digital media to organic fusion with internal stimuli, as long established with digitally controlled pacemakers, or as envisioned in neurochips. In contrast, people experience the classic sustainability questions, as complex as they are, as easier to judge. "How much money or sacrifice am I willing to invest in climate protection?" While this is a serious question in terms of its implications, it is experienced by most people as one that can be answered relatively consistently. "How much information about my body and psyche do I want my health care providers to have about me?" – this question remains essentially unanswerable for those affected. It is all the more remarkable that companies and politicians have made progress in recent years in regulating the value trade-offs and conflicts associated with such challenges. In the process, ethics is increasingly proving to be an instrument for dealing with uncertainty and insecurity.

Learning from ethics

Ethics helps in dealing with uncertainty. Jürgen Habermas has placed the discourse at the centre of his theory of communicative action.[10] In this context, he formulates the principle of universalisation as follows: "Thus every valid norm must satisfy the condition that the consequences and side-effects, which in each case (presumably) result from its *general* observance for the satisfaction of the interests of *each* individual can be accepted (and preferred to the effects of the known alternative possibilities of regulation) by *all* concerned." [11] This principle equally reinforces

RECOMMENDED READING

A. Winter, F. Esselmann, A. Brink, C. C. Germelmann: Menschenzentrierung als Ziel des Verbraucherschutzes im digitalen Kontext. Mit einem Higher Purpose in die praktische Umsetzung, in: S. Roth, H. Corsten (eds.): Handbuch Digitalisierung. München 2021 (in press).

A. Brink: Digitalethik, in: M. S. Aßländer (ed.): Handbuch Wirtschaftsethik, 2. überarbeitete Auflage. Stuttgart 2021 (in press).

Fig. 2: Effective internal communication within companies is a prerequisite for successful communication with external stakeholders (Photo: ist).

both the shared value and the multi-stakeholder perspectives. It is embedded in Habermas' public communication on values, which intends to reduce uncertainty, increase the acceptance of norms, and create trust. In the good old Kantian tradition, the human being is at the centre of his or her ethics.

Nevertheless, the universalisation principle proposed by Habermas must also be viewed critically, especially in the context of the digital transformation:

- Even the reference to "presumably" consequences and side effects is problematic. As the British technology researcher David Collingridge has determined, the consequences of a technical development are often only foreseeable when this development has progressed so far that it is hardly possible to change course.[12] This "Collingridge dilemma" also applies to innovation in the field of digitalisation and artificial intelligence.

- The universalisation principle, in the formulation proposed by Habermas, requires that "all" who are potentially affected by a decision participate in a discourse. However, digitalisation and its consequences in particular include almost all the people of the world. It was not least such rather unrealistic demands on an "ideal discourse" that sparked the criticism of Habermas' universalisation principle.

- The digital transformation calls into question the realism of this principle in yet another respect. Today, *strategic action* dominated by interests rather than *communicative action* oriented towards comprehensibility, truth, correctness, and truthfulness dominates in government, business, and society. Therefore, the consensus sought in communicative action – understood as coherence of the convictions held by the participants – is often replaced in lived practice by a negotiation-based or consultative compromise.[13]

- The discourse demanded by Habermas, which is meant to establish the validity of norms, requires all participants to put aside their respective individual interests. But conversely, it is precisely the personal involvement of various shareholders and stakeholders that makes communication focused on people necessary in the context of digital transformation.

However, these reservations about Habermas' theory of communicative action do not render his approach of placing communication at the centre of ethics obsolete. On the contrary, this approach can prove fruitful and promising especially in the field of CDR. This is especially true when no "neutrality" is expected from those involved, but when their personal involvement forms the starting and connecting point for a human-centred communication concerning new digital technology. Consumers, customers, clients, citizens, patients, or residents should be able to include their individual perspectives, interests, and also prejudices in the necessary communication processes. Principles, norms, and values often have the function of regulating these processes with the aim of enabling well-founded and widely accepted compromises and thereby strengthening mutual trust. The CDR Code, which emerged from the CDR initiative of the Federal Ministry of Justice and Consumer Protection, is a good example in this context.

An important goal of these ethically regulated processes must be to strengthen digital autonomy under the conditions of the ambivalence of digital technology and the irresolvable Collingridge dilemma. Communication is the appropriate means, and consistent human-centredness the underlying principle. Habermas calls for the "recognition of the other in their otherness". However, this mutual recognition can only be realised if there is a high degree of transparency. In the context of the digital transformation, this prerequisite is very demanding.

Photo: ist.

AUTHORS

Prof. Dr. Dr. Alexander Brink is Professor of Business Ethics at the University of Bayreuth. He has headed the newly founded Institute for Ethics & Management here since 2021.

Frank Esselmann is a partner at concern GmbH, a spin-off of the University of Bayreuth, and works as a management consultant with projects in the USA and Europe for companies in various industries.

A good example: The Data Process Modeler enables transparency on technology and values

The Data Process Modeler was developed on behalf of Bayern Innovativ, funded by the Bavarian State Ministry for the Environment and Consumer Protection, as an open-source solution with the task of supporting companies in making their data processing transparent in processes, goals, and value questions – from security to the implementation of e.g. autonomy and human-centredness. The solution allows a visual presentation supported by icons, images, and videos, which, starting with a simple overview, can be "unfolded" in depth as needed.

The special added value of the approach lies in the fact that all those involved, from affected laypersons to representatives and experts, have the same information basis. For example, when it comes to the development of digital health applications, patients, doctors, and family members as well as experts with IT and health expertise have the same information at their disposal. The Data Process Modeler has proven to be highly beneficial for communication, trust, and acceptance.

https://www.bayern-innovativ.de/seite/data-process-modeler

But it can be realised, as a current development from Bavaria – the Data Process Modeler – shows.[14]

Two conditions for effective communication

Two conditions are particularly important for successful communication with consumers:

Communication must be comprehensible –
in concrete terms, this means that companies should

- revise the language of their specialist jargon and
- ensure seamless communication between specialists at all levels and all stakeholders.

Communication has to be learned –
in concrete terms, this means that companies should

- develop a strategy for customer literacy including materials,
- hone their judgement to clearly distinguish between social and personal dimensions,[15]
- develop a good, validated methodology for assessing digital technologies with scientifically sound and ethically justified involvement of the people and stakeholders concerned,
- use market research methods, for example in relation to the "Digital Moment of Truth", and also use the Critical Incident Technique (CIT) to identify behaviours that positively or negatively influence the results of communication processes.

Conclusion

The speed of the digital transformation will continue to increase, as will uncertainties, conflict, and ambivalence. Consumer involvement will be the task of the future, for which new tools will have to be developed. There is reason to be confident that great progress can be expected in this area. Whether they will be enough to counteract a further polarisation of society or the widening "digital divide" remains to be seen.

1 F. Esselmann, A. Brink: Corporate Digital Responsibility. Den digitalen Wandel von Unternehmen und Gesellschaft erfolgreich gestalten. In: Spektrum. Das Wissenschaftsmagazin der Universität Bayreuth (2016) 12 (1), 38–41, und T. Cooper, J. Siu, K. Wei, in: Accenture (ed.): Corporate Digital Responsibility. Doing Well by Doing Good. London 2015.
2 EU (2021): Neue Vorschriften für künstliche Intelligenz – Fragen und Antworten. https://ec.europa.eu/commission/presscorner/detail/en/QANDA_21_1683.
3 https://www.de.digital/DIGITAL/Redaktion/DE/Dossier/digital-gipfel-2019.html (30.09.2021).
4 https://www.cdr-award.digital/ (30.09.2021).
5 See Infobox p. 72.
6 F. Esselmann, D. Golle, A. Brink (2020): Whitepaper Corporate Digital Responsibility. Garching. Online published under: https://www.bayern-innovativ.de/seite/corporate-digital-responsibility-cdr
7 https://www.cdr-building-bloxx.com/ (30.09.2021).
8 ConPolicy (2021): Corporate Digital Responsibility. Ergebnisse eine repräsentativen Verbraucherbefragung. Published under https://cdr-initiative.de/news/cdr-auf-dem-digital-gipfel-2020-digital-nachhaltiger-leben-2
9 A. Winter, F. Esselmann, C. C. Germelmann (2021): Menschenzentrierung als Ziel des Verbraucherschutzes im digitalen Kontext, see recommended reading.
10 J. Habermas: Theorie kommunikativen Handelns. Suhrkamp, Frankfurt 1984.
11 The original German text reads: „So muß jede gültige Norm der Bedingung genügen, daß die Folgen und Nebenwirkungen, die sich jeweils aus ihrer *allgemeinen* Befolgung für die Befriedigung der Interessen eines *jeden* Einzelnen (voraussichtlich) ergeben, von *allen* Betroffenen akzeptiert (und den Auswirkungen der bekannten alternativen Regelungsmöglichkeiten vorgezogen) werden können." J. Habermas: Moralbewusstsein und kommunikatives Handeln. Suhrkamp, Frankfurt 1983, 75 (Italics A.B. und F.E.).
12 D. Collingridge: The Social Control of Technology. New York 1980.
13 Cf. basic to digital ethics: A. Brink (2021): Digitalethik, see recommended reading.
14 See Infobox p. 75.
15 D. J. Solove: The Myth of the Privacy Paradox, in: George Washington Law Review (2020), Vol. 89, 1-42.

Martin Weibelzahl

Flexibility in times of increasing uncertainty

A plea for the expansion of sustainable and flexible energy systems

Wind power will be able to make an important contribution to making energy systems more flexible (Photo: ist).

Energy lies at the very foundation of economic prosperity, indeed of our society in general today – including education, nutrition, and our leisure time activities. The COVID-19 pandemic, with its severe economic and social consequences, has shown how crucial reliable energy supply is in times of crisis. Within only weeks of the outbreak of the pandemic, the severe economic crisis had a violent impact on electricity systems – both on the supply and the demand side. General electricity consumption fell, consumption profiles in industry and households suddenly changed, and fuel prices dropped. Nevertheless, early indications are that in many countries around the world, electricity systems continued to function without widespread failure.[1] Accordingly, if one looks at the COVID-19 pandemic as a stress test of the resilience of global power systems, one might come to the tentative conclusion that overall, power systems have stood up well.

Nevertheless, it would be a fallacy to think that the resilience of our power systems is so high that stable and reliable power supply can be guaranteed in the future without major system changes.[2] This is because a closer look reveals a whole series of uncertainty factors: The switch from high-carbon to low-carbon systems and a growing share of renewable energies tend to make the operation of power systems much more uncertain, regardless of how important they are to environmental and climate protection. The amounts of electricity generated from wind power and photovoltaics are subject to strong, often unpredictable weather- and climate-related fluctuations. However, the physical laws that govern electricity grids require that electricity supply and demand be in balance – for every single millisecond and at every single location of the electricity grid. Consequently, fluctuation poses a particular challenge. Technical solutions must be found for the stable operation of future "green" power systems.

System costs are already very high right now. For example, the costs of corrective measures in Germany regularly amount to over one billion euros per year. Such costs are regularly passed on directly to end consumers, posing a challenge to the overall affordability of electricity. Our experience of the COVID-19 pandemic and the resulting economic crisis, as well as the challenges posed by climate change, indicate the direction in which the development of energy systems should move in the future: The key concept here is "flexibilization".

Making energy supply (more) reliable

The flexibility of an electricity system is, in simple terms, its ability to react to changes in supply and demand in such a way that spatial and temporal balance in the respective underlying electricity grid is guaranteed. Only if an electricity system is able to do this does it have the necessary stability and resilience. This is why public and private investment in making electricity systems more flexible is urgently needed worldwide. They have the double advantage of the energy and climate goals aimed for in politics and society being achieved (faster), and of electricity systems contributing to facilitating long-term economic growth.

There are numerous recent examples of the catastrophic consequences of widespread power outages. In 2012, around 600 million people were without electricity as a result of two major blackouts in India. Then in 2019, Argentina, Paraguay, and Uruguay were hit by massive cascading blackouts. There were massive cost hikes everywhere as a result. They were not only caused by the grid interventions necessary and the direct restoration of supply security, but also, for example, by repair work on the production facilities of industrial companies. In most countries, these costs are passed on to private households in particular, meaning the danger of so-called energy poverty increases. In this context, academic literature repeatedly points to the central importance of a socially responsible governance framework for technologically advanced electricity systems. Laws, regulations, and other rules must set the right incentives to strengthen the resilience of electricity systems. This includes, first of all, incentives for the steady expansion of, for example, storage technologies. But other options with which power systems can react flexibly to variability on the supply side – caused by the increased feed-in of renewable energies – must also be explored.

"Worldwide, public and private investment in making electricity systems more flexible is urgently needed."

Five important technical flexibility options can be distinguished that must be developed in future electricity systems:[3]

AUTHOR

Dr. Martin Weibelzahl is a post-doctoral researcher at the Faculty of Law and Economics at the University of Bayreuth, and a senior staff member of the Project Group Business & Information Systems Engineering of the Fraunhofer FIT (© B. Seitz).

RECOMMENDED READING

S. Halbrügge et al.: How did the German and other European electricity systems react to the COVID-19 pandemic? Applied Energy (2021), 285, 116370. DOI: 10.1016/j.apenergy.2020.116370.

R. J. Heffron et al.: The role of flexibility in the light of the COVID-19 pandemic and beyond: Contributing to a sustainable and resilient energy future in Europe. Renewable and Sustainable Energy Reviews (2021), 140, 110743. DOI: 10.1016/j.rser.2021.110743.

Operations Research

For about a century, the field of Operations Research, or OR for short, has been concerned, in particular, with the development and use of models and methods to solve complex real-world problems. In this way, it supports, for example, the decision-making processes of companies or political decision-makers. OR uses approaches from (applied) mathematics, economics, and computer science.

In the course of the energy transition to renewables, a large number of complex short- and long-term decisions have to be made in order to quickly decarbonise the economy and society, while sustaining high levels of supply security and affordability of electricity. In this context, the interdisciplinary field of OR can provide important support by means of quantitative models and, for example, allow various decision alternatives to be compared. Uncertainties and risks can be modelled and thus actively included in the decision-making process.

- Supply-side flexibility, for example, through highly efficient and modern gas-fired power plants
- Transmission flexibility through a coordinated expansion of the electricity grid
- Demand-side flexibility, especially through intelligent control of industrial processes
- Intersectoral flexibility by linking the power sector with other sectors such as transport or heating
- Storage flexibility, for example through new battery technology

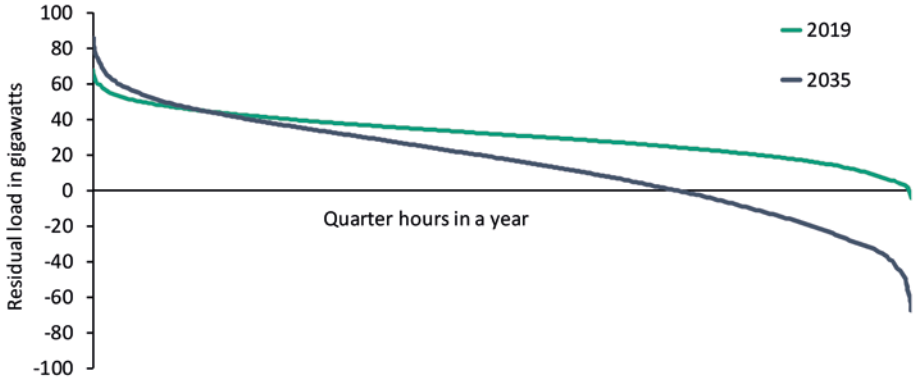
In many countries, the demand for flexibility caused by renewable energies is additionally driven by the phase-out of conventional power plants. In Germany, coal-fired power plants currently still provide a large part of the necessary flexibility of the energy system on the supply side, and can contribute to relieving grid bottlenecks. In addition, the ongoing electrification in areas traditionally based on fossil fuels, such as the transport sector, is causing electricity demand to rise and requires further expansion of volatile renewable sources.[4]

Against this backdrop, European transmission system operators are forecasting an increasing need for flexibility over the coming years. Researchers speak of a "flexibility gap", which is already becoming apparent today. Fig. 1 shows the residual load for Germany in 2019 and 2035. The residual load describes the difference between electricity consumption and the corresponding generation from renewable energy sources, and can be seen as a measure of the balancing need that must be satisfied by the flexibility options described above. The changes in residual load between 2019 and 2035 shown in Fig. 1 underline the increasing need for flexibility over the coming decades due to growing demand and supply imbalances.[5]

This challenge must be specifically addressed by policy-makers at national, European, and global levels with new concepts and measures for the expansion of flexibility – commensurate to targets regarding the expansion of renewable energy, such as those already adopted in Germany. The medium and long-term view is also crucial here. Short-term mechanisms to strengthen flexibility alone are not enough, as much as they have proven themselves recently. Rather, large-scale investments in flexibility are essential.

In parallel, the term "flexibility justice" is gaining more and more importance in the international debate. Central to this is the demand that all stakeholders should be involved when it comes to the design and realisation of flexible electricity systems as well as the provision of flexibility and the trading of flexibility. In addition, there should be a fair distribution of the associated costs and revenue opportunities in a future electricity system. All *stakeholders* should be involved in the formulation of energy legislation and in regulatory projects that are suitable to promote progress towards low-carbon, resilient, and equitable electricity systems.

Fig. 1: German residual load in 2019 and 2035 based on Buhl et al. (2021)[5] (Graphic: Martin Weibelzahl).



■ *Fig. 2: Solar panels on the roof of an industrial building (ist).*

Need for political action

The governments of the member states of the European Union have reacted to the economic slump triggered by COVID-19 with extensive rescue and economic stimulus programmes. An equally strong commitment should now be made to the energy transition to renewables, which should also be understood as a flexibility transition. The political momentum that has developed in the course of the fight against the pandemic offers a good prerequisite for this. It should now be harnessed and continued in developing proactive economic and energy policy, in order to integrate incentives for investment in flexibility. At least as a kind of bridging technology, gas-fired power plants will undoubtedly play an important role in future energy systems, as they are technically capable of ramping up quickly and emit significantly fewer greenhouse gases than coal-fired power plants. However, policymakers should, for example, create stronger incentives than in the past for "green" gas – i.e., gas produced from renewable sources – to be used in the energy system. Decision-makers in government and business must not lose sight of the overall goal of the energy transition, the decarbonisation of the energy system. It is important to avoid permanent dependence on technology that may have a short-term advantage, for example in providing flexibility, but in the long term fall short of the necessary (and in principle also achievable) goals of the energy transition.

This should be remembered especially in view of the consequences of COVID-19. The pandemic-related decline in industrial production led to a demand shock in the energy sector, which caused the prices for fossil fuels to drop temporarily. This development temporarily increased the competitiveness of those flexibility assets that run with these fuels and emit greenhouse gases. Indeed, during the COVID-19 pandemic, some utilities procured oil and gas, sometimes on a massive scale, and even built new tanks to store fuels. As a result, the economic prospects for non-fossil flexibility options declined at the same time. The consequence was growing uncertainty among those investors who were already prepared for a "green" flexibilization of the energy sector. Against this background, it is now crucial to (re)establish and improve investment security for this sector, as synergies with national climate policies and measures can create a coherent investment climate.

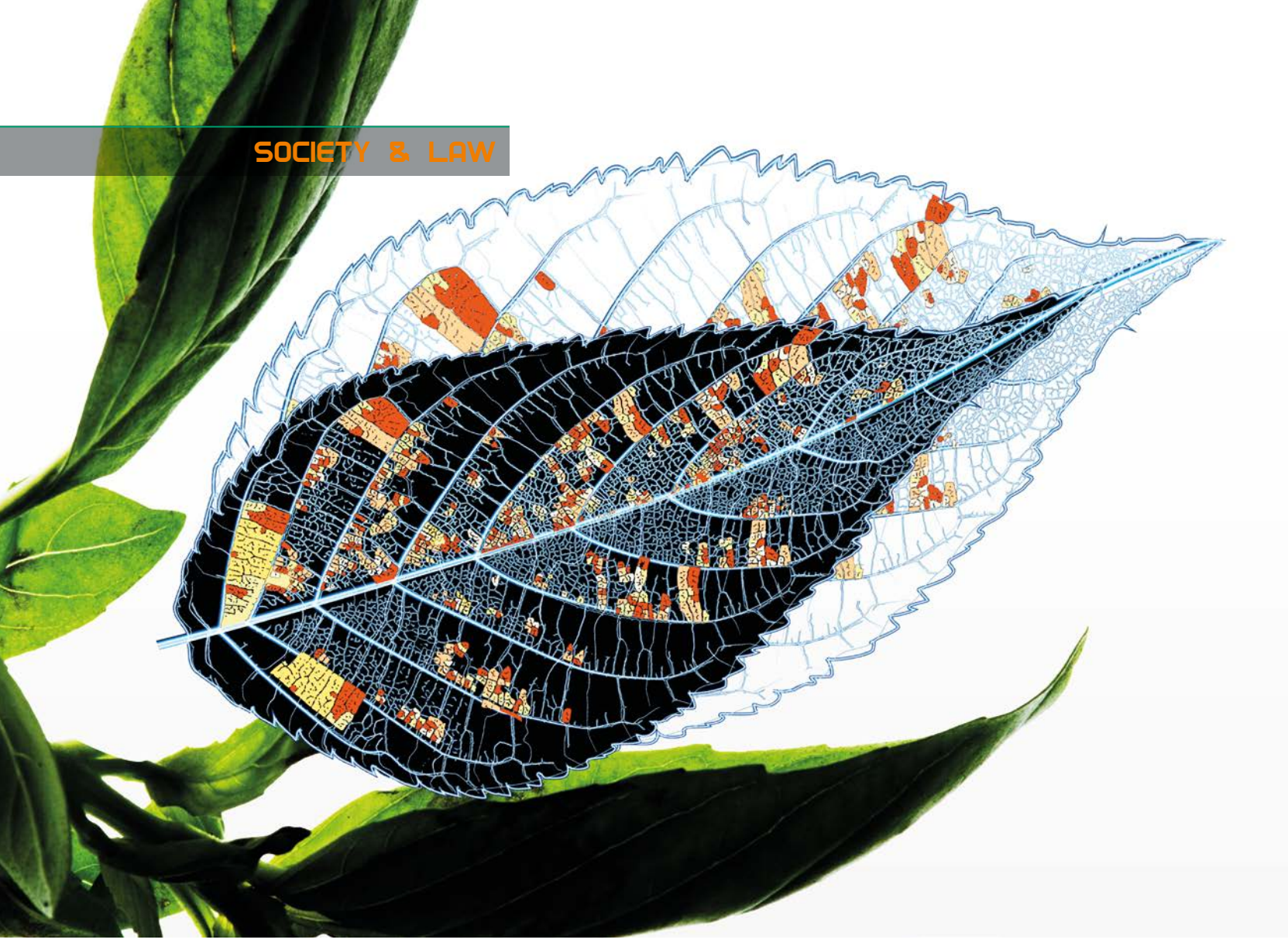
Not least, recent developments in Germany underline that this is a realistic option. Despite the negative economic impacts of the pandemic, political leaders have followed the recommendations of a coal phase-out commission that incorporated the expectations of key stakeholders. A law for a coal phase-out by 2038 was drafted to pave the way for an equitable transition to a low-carbon economy. This was flanked by various resolutions and political initiatives in Germany and at the European level. In this context, access to affordable, reliable, and sustainable energy must be guaranteed for all – not only in the Western industrialised countries, but worldwide. Currently, global cooperation aimed at enabling developing countries to build sustainable, flexible energy systems is very promising. It is undoubtedly a key to the gradual realisation of "Agenda 2030" and its sustainability goals, as adopted by the United Nations.

Energy-flexible factories of the future

Dr. Martin Weibelzahl is head of the Copernicus project SynErgie, which is funded by the German Federal Ministry of Education and Research (BMBF) and deals with the design of a sustainable energy system. In particular, the energy-intensive industry in Germany with an electricity consumption of about 40 percent has enormous potentials to compensate fluctuations of renewable energies by energy-flexible processes. In the project, Dr. Martin Weibelzahl is investigating the regulatory changes needed to harness the flexibility potential of German industry.

www.kopernikus-projekte.de/en/projects/synergie

1 S. Halbrügge et al.: How did the German and other European electricity systems react to the COVID-19 pandemic?, see recommended reading.
2 R. J. Heffron et al.: The role of flexibility in the light of the COVID-19 pandemic and beyond: Contributing to a sustainable and resilient energy future in Europe, see recommended reading.
3 See also E. M. Ländner et al.: From energy legislation to investment determination: shaping future electricity markets with different flexibility options. Energy Policy (2019), 129, 1100-1110. 10.1016/j.enpol.2019.02.012 – R. Heffron et al.: Industrial demand-side flexibility: A key element of a just energy transition and industrial development. Applied Energy (2020), 269, 115026. DOI: 10.1016/j.apenergy.2020.115026.
4 G. Fridgen et al.: A holistic view on sector coupling. Energy Policy (2020), 147, 111913. DOI: 10.1016/j.enpol.2020.111913.
5 H. U. Buhl et al.: Bewertung von Flexibilitätsoptionen im deutschen Stromsystem 2021 bis 2035 unter Berücksichtigung der Holzverfeuerung. Projektgruppe Wirtschaftsinformatik des Fraunhofer-Instituts für Angewandte Informationstechnik FIT, Augsburg/Bayreuth 2021.



Alexandra Molitorisová
Kai Purnhagen

Dealing with uncertainty in legislation

On the regulation of genetically modified organisms in the EU

Gene editing offers new possibilities for specifically modifying the structure of plant DNA and thus its properties (Photo: ist).

In July 2021, an article appeared in the *New York Times Magazine* under the headline of "Learning to Love G.M.O.s" that dealt with the public acceptance of food containing genetically modified organisms (GMOs).[1] In it, author Jennifer Kahn proposed a new perspective. As a result of gene editing, she argues, niche markets have emerged for products that are quite different from conventional GMO-based foods. These products are produced by small farms, processors, and laboratories that look for specific characteristics in plants and foods – be it a particular nutrient, an unusual taste, or a specific medicinal effect. Furthermore, plant varieties can be adapted to local conditions with the help of gene editing. For example, where there is a shortage of labour, the growth of cherry trees can be influenced so that the fruit is easier to pick. Where there is a threat of frost and heavy rainfall, it is even possible to grow cherries all year round. In addition, flavours and aromas can be rediscovered by re-growing lost plant varieties. Gene editing seems capable of opening up almost unlimited possibilities for new products and markets.

Here, a difference to earlier genetic engineering methods becomes apparent. Traditionally, GMOs have mainly been characterised by traits that lead to higher yields under conditions of increased pesticide resistance. These agricultural advantages can also be achieved with the help of gene editing, which in this way contributes to global sustainability. However, global sustainability is more likely to be perceived as an *indirect* benefit by most consumers – and only if they are aware of basic links between yields, pest control, land, use and biodiversity. In contrast, the new technologies of gene editing promise consumers *direct*, tangible benefits: new experiences, previously unknown flavours, more nutrients, and improved health. But are these benefits of gene editing sufficient to justify a new "more liberal" regulatory framework for GMO-based foods? And if so, can these benefits alone persuade consumers to accept gene editing?

Decisions under the influence of prejudice

Recently, there has been growing dissatisfaction with the status quo of the legal regulation of GMOs in the EU, and the push for improvements is meeting with increasing support – particularly within the scientific community, as the benefits of gene editing and its societal importance become increasingly clear. The current legal situation in the EU, which severely restricts the use of gene editing in food production, was undoubtedly created in good faith. However, it may be based on misunderstandings that modern behavioural science calls "biases". In this context, biases that influence decision-making are considered a deviation from the model of a rational agent. According to this model, when people are guided by biases - for example, as members of the legislature enacting legal regulations or as citizens guided by these regulations – they do not act rationally. Their action-determining prejudices prove to be persistent and resistant, even when times change. Even a legislature is not immune to prejudice, except at certain points in time. Often the same prejudices are passed on from one generation to the next - without being recognised as prejudices. Nor is it the case that the legislature in a democracy is less susceptible to prejudice than its citizens. As a constitutional body whose members are elected, it reflects the prejudices, preferences, and fears of the electorate.

An example of a long-lasting prejudice is the widespread idea that nature is in principle benign or benevolent, while human intervention endangers health or the environment. It is possible that this view has even influenced EU legislation. It may be that it has since changed in light of the Covid 19 pandemic, especially considering the origin of the virus (nature) and the technology underlying vaccine development (gene editing). Whether the pandemic will thus also contribute to a long-term weakening of existing prejudices against genetically modified food remains to be seen.

RECOMMENDED READING

K. Purnhagen: The Behavioural Law and Economics of the Precautionary Principle in the EU and Its Impact on Internal Market Regulation. Journal of Consumer Policy (2014), 37, 453-464. DOI: 10.2139/ssrn.2344356.

A. Tor: The Methodology of the Behavioral Analysis of Law. Haifa Law Review (2008), Vol. 4, 237.

K. Purnhagen et al.: Europe's Farm to Fork Strategy and Its Commitment to Biotechnology and Organic Farming: Conflicting or Complementary Goals?, Trends in Plant Science (2021), Vol. 26 (6), 600-606. DOI: 10.1016/j.tplants.2021.03.012.

Fig. 1: Low cherry trees allow for faster harvesting (Photo: ist).

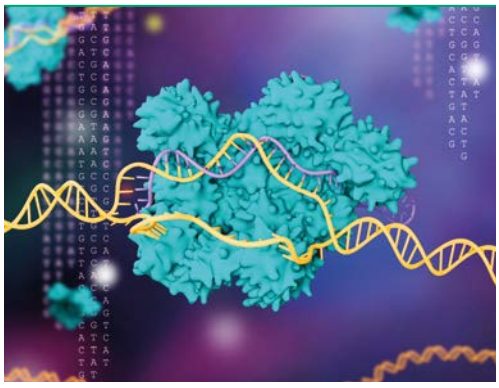


Fig. 2: 3D illustration of CRISPR-Cas9 gene editing technology (Image: ist).

Another example is the strong aversion to losses and threats to the status quo. It makes not only individuals but also legislators act preventively and precautionarily instead of primarily considering the possible benefits of new technologies. In doing so, legislators tend to neglect certain risks. For example, overemphasising the risks of new technologies to human health can lead to other risks being lost sight of - not least the risk that potential benefits of these technologies will be wasted.

"Many consumers are not aware of the difference between gene editing with the help of "gene shears" and older methods of genetic engineering, so they consider genetically modified organisms to be fundamentally unsafe."

If the legislature allows itself to be determined by such prejudices, it will very soon find itself in an impasse from which there is no easy way out. Even a moderate change in the existing legal situation is not so easy, and a shift to a flexible, proactive form of regulation – "forward-looking, results-oriented, experimental, responsive, cooperative" [2] – is even more difficult. Legal regulations are supposed to be relatively consistent, and it must be foreseeable that people will generally behave as they are expected. However, it is precisely this consistency and predictability that poses a problem. Regulation that guarantees the safety of a product signals to consumers that, in principle, all products covered by that regulation are potentially unsafe or even dangerous. This generalisation is particularly problematic if, on the one hand, long-standing and, on the other hand, newly emerging technologies are used to manufacture the products, whose different modes of operation are not known to consumers. This also applies to legal regulations concerning the use of GMOs in food production. Many consumers are not aware of the difference between gene editing with the help of "gene shears" and older methods of genetic engineering, so they consider genetically modified organisms to be fundamentally unsafe.

The *New York Times Magazine* article cited above attributes this misconception to the fact that most people fundamentally misunderstand how genes work. But this may not be the only reason. For today there is also a lack of knowledge in other areas that is necessary for an appropriate assessment of gene editing. For example, knowledge about the breeding of plants and animals, and their significance for the development of humankind, is often no longer available. One example is that genetic mutations that were disadvantageous from another species' point of view, because of their negative selection value, were nevertheless systematically bred because they proved useful to humans in one way or another. A deeper knowledge of these relationships could help to change public attitudes towards GMOs.

Uncertainty due to legal regulations

Predictability and consistency in legislation do not seem to sit well with a wise, prudent, and flexible approach to the question of causal relationships between technology-related risks and expected harms. Legislation requiring a safety assessment for the marketing authorisation of products of a certain category is likely to discourage consumers from buying these products. There is a high likelihood that they will be fearful of all products in this category.

The GMO approval process in the EU, which mixes scientific and political assessments, is such that very few GMO-based foods have been approved within the EU over the last 30 years. A *positive* authorisation process, based not only on the absence of hazards

Fig. 3 and 4: In the focus of consumers: Food ingredients (Photos: ist).

but on demonstrable *benefits* for consumers, is sorely lacking. This deficit reinforces feelings of uncertainty, aversion, and fear towards GM products. And whenever people are uncertain, they look for causal links. This leads them to make an unreflective causal link between GMO-based foods that require regulatory approval and dangers to human health. This tendency is reinforced by the fact that – as mentioned above – the traditional use of GMOs in food production has mostly benefited consumers only in an *indirect* way.

The current EU regulatory framework, which applies equally to traditional genetic engineering practices and gene editing, contains yet another problem. Strict regulation implies a high regulatory burden, and a high regulatory burden can in turn only be borne by large, well-funded companies. However, it is precisely the advocates of strict GMO regulation who are particularly suspicious of large companies.

"De-biasing": a pioneering approach from behavioural research

There is thus ample evidence that the EU's restrictive GMO regulations reflect the characteristics of prejudiced decision-making as identified by behavioural research. If this explanatory approach is correct, behavioural research may also be able to contribute to paving the way out of this impasse. Above all, the following insight should be helpful. If prejudiced decisions are made under a given set of circumstances, the targeted reduction of prejudices ("de-biasing") is a suitable instrument to promote the emergence of well-founded legal regulations.[3] This de-biasing can take legal and non-legal forms. A non-legal means is active communication, which makes the respective stakeholders aware of their prejudices and enables them to make better – because unbiased – decisions.

■ *Fig. 5: Genetically modified plum variety resistant to Scharka virus (Photo: wikimedia commons / Scott Bauer, USDA ARS / PD).*

Following this approach, the think-tank "Re-imagine Europe" is investigating the potential for reducing prejudices in the GMO debate on a European level.[4] In addition, one other finding of behavioural research should be used. If prejudices are omnipresent in a system of legislation and influence decision-making, this system should be examined to see what potential *it itself* contains to free decision-makers from prejudices and prevent erroneous decisions as far as possible.[5]

A well-known example of how prejudiced decisions can be pushed back by legal regulation can be found in internet commerce. Consumers have the possibility to reconsider already made purchase decisions within the following 14 days and, if necessary, to reverse them without adverse consequences. Similarly, the law could also give those responsible for legal regulations the opportunity to review their decisions. They often have to make their decisions quickly and in accordance with the expectations of various stakeholders. Biases easily enter into decision-making in these circumstances. One tool to keep legal regulations as free from bias as possible could be to grant a "cooling-off period" – in the way that legislative and regulatory decisions are given an expiry date when they are published. EU authorities could issue guidelines stating that decisions taken should be reviewed by the expiry date to see whether and to what extent they are motivated by prejudice. If the legal act in question is based on Article 114 of the Treaty on the Functioning of the European Union, as is the case with most GMO legislation in the EU, "debiasing through law" may also reflect the possibility of adapting measures to harmonise the legal situation in the EU to the current state of scientific knowledge.

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1 https://www.nytimes.com/2021/07/20/magazine/gmos.html (29.09.2021)
2 https://civilservice.blog.gov.uk/2021/01/20/a-brave-new-world-agile-regulation-to-unleash-innovation/ (29.09.2021)
3 A. Tor: The Methodology of the Behavioral Analysis of Law. Haifa Law Review (2008), Vol. 4, 237-327, mit Verweis auf C. Jolls and C. R. Sunstein: Debiasing through Law. Journal of Legal Studies (2006), Vol. 345(1), 199-242.
4 https://reimagine-europa.eu/ (29.09.2021) re-imagining-european-agri-culture.
5 „(T)he legal analyst must go still farther and examine the potential of the legal system actively to debias decision makers and thereby eliminate or reduce decision errors", in: A. Tor, see n. 3, here: 293.

Carsten Bäcker

Uncertainty in law

Of the ascertainable and the to-be-ascertained

Jurisprudence differs from other norm sciences in that the subject matter to be interpreted is associated with a legal claim to validity (Photo: ist).

Uncertainty is nothing unusual. It confronts lawyers

- as epistemic uncertainty, at the level of the ascertainment or ascertainability of facts, and
- as normative uncertainty, at the level of the ascertainment or ascertainability of the normative content of legal propositions.

The first form of uncertainty plays virtually no role in legal education; it only comes as a shocking surprise to university-trained lawyers when they enter practice. However, it is not an uncertainty exclusively reserved for jurisprudence, even if it has a special meaning in law. The second form of uncertainty is more exclusive. It characterises jurisprudence, which is primarily concerned with legal provisions and the norms they contain, in a categorical way. Consequently, this normative uncertainty also plays a greater role in education; however, it is not reflected upon enough. In the course of legal studies, it is sacrificed to the unspoken claim to correctness of the supposedly unambiguous legal situation as described in case studies in German legal education. The following lines will take a closer look at both uncertainties and how the law deals with them, and draw some consequences for jurisprudence that can be derived from them.

On epistemic uncertainty

Understood as uncertainty about what has happened, epistemic uncertainty shapes the activity of lawyers in practice. The determination of what has happened is the logical prerequisite for the legal evaluation of what has happened. Therefore, in legal practice, the first step is to establish (not to determine) the facts of the case: What has happened? This challenging task is almost completely ignored in the study of law; instead, it is taught in dry runs, as it were, to find a legal solution to a given set of facts. The legal traineeship provides upcoming lawyers with their first attempts to swim, albeit still only very marginally – for example, in the form of legal psychology courses on examining witnesses, conducting an oral court hearing, or even attending a police house search. However, the skills for determining what has happened are ultimately only learned in practice, or more precisely acquired in the process.

For example, a criminal judge makes their decision on the basis of an established fact – the existence of which is never completely certain, something which the judge knows for sure. For with sufficient imagination, any sequence of events, even if only in the belief in the supernatural, could be explained by causal connections that exonerate the perpetrator. Thus, the fist of perpetrator T in the face of victim O at time Z at place Y may be proven by the testimony of eyewitness A; but who is willing to exclude that all three had perceptual disturbances and were in fact at place X, where the fist of A struck O, observed by T? Or could O, most unhappily, have brought his own fist to strike his eye, perhaps driven to do so by an imaginary friend (worth watching: the TV series "happy!").

"Lawyers have to make assumptions despite uncertainty if they wish to legislate for the future."

It is even possible that we all live in a "matrix", in a reality simulated by computers, as was suggested to us by the Wachowski brothers in the film of the same name shortly before the turn of the millennium. Then basically nothing of what we remember would ever have really happened, it would all always just be implanted imagination, virtual reality. A judge who was convinced that we are all only virtual participants in a fantasy world that an artificial intelligence machine makes available to us only in order – as in "Matrix" – to satisfy its otherwise insatiable hunger for energy would certainly be a problematic judge; especially if they were no longer willing to do justice to their role, at least in this supposedly virtual reality.

The law, however, does not even get involved in such fantastic uncertainties. It demands the truth – but is satisfied if the judge is convinced of the course of events on the basis of the evidence presented at the oral hearing; beyond reasonable doubt. In this way, the law declares a certain, regularly unavoidable degree of uncertainty to be irrelevant in order to be able to fulfil its functions, for example, the administration of criminal justice. The right to ascertain the truth is reflected, for example, in section 244 (2) of the Code of Criminal Procedure (StPO): "In order to ascertain the truth, the court shall, of its own volition, extend the taking of evidence to all facts that are of importance for the decision". However, the genuflection before uncertainty is then shown in section 261 of the Code of Criminal Procedure: "The court shall decide on the result of the taking of evidence according to its free conviction drawn from the es-

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Fig. 1: Scene from the 1957 film classic "The Twelve Juries": The jury must reach a unanimous verdict on the guilt of an 18-year-old Puerto Rican accused of murdering his father. If found guilty, he faces the death penalty (wikimedia commons).

sence of the hearing". Truth follows function; decisions must be made even if the truth remains uncertain. The criminal judgement is, consequently, based on the "facts considered proven", § 267, paragraph 1 of the Code of Criminal Procedure; which are thus determined in a certain way in the process of legal decision-making.

Another typical situation of legal decision-making under epistemic uncertainty is that of determinations for the future. As a rule, the law regulates situations that will only occur tomorrow. This naturally applies to planning decisions that designate a future use of land, but also to imperative or quasi-imperative rules of conduct, such as administrative offences and criminal provisions, which as a rule have an effect for the future. Admittedly, retroactive legal regulations are just as conceivable as they are possible in principle, but these are already problematic under constitutional law and are completely ruled out in criminal law, Art. 103 II GG. Retroactive regulations would also hardly serve the purpose of shaping the law. For the past can no longer be changed; at best, its perception in the present and its evaluation in the future can be influenced. And yet regulations that only take effect in the future are hermeneutically inevitably linked to experiences from the past, to which the uncertainties described above in exaggerated terms apply. But for regulations of the future there is a separate kind of uncertainty. Here we must not only reckon with the fact that our perception of what has happened differs from what has actually happened (insofar as we can recognise this difference at all), but also assume that no one can ever say with certainty what will happen in the future. Forecasts are per se prone to error, as weather forecasting teaches us, and they are all the more prone to error the more complex the forecast is. But it would be a mistake to completely ignore forecasts like the weather report simply because they are prone to error.

In any case, lawyers do not have this option if they wish to issue regulations for the future. They then have to make assumptions in a state of uncertainty. This is the original task of government or the institutions appointed to do so in the legal system. However, it is up to lawyers to transform political decisions made on the basis of certain assumptions into legal rules. The political decisions cast in legal statutes are then also subject to judicial, i.e. legal, review. One example is the decision of the First Senate of the Federal Constitutional Court on the Climate Protection Act of 24 March 2021, in which Germany's highest court – spectacular in terms of climate and socio-political aspects and also shaking up legal dogma – declared the existing statutory regulation covering the period until 2030 unconstitutional. This regulation, according to the reasoning, will have to lead to considerable impairments of the complainants' fundamental rights in the future that is not (!) regulated, i.e.: after 2030, according to the available forecasts on climate change. It can be inferred from this argumentation that decisions with effect for the future must be made on the basis of present, inevi-

tably epistemically uncertain forecasts and can be controlled thereupon – in the sense of Art. 20a GG *in dubio pro futuro*.

On normative uncertainty

Normative uncertainty is a completely different thing. Lawyers encounter it in the core of their activity: the attempt to determine the normative statements in legal sentences. Legal texts are written in language. Language requires decoding in order to determine the meaning conveyed by language. This process of decoding is that of interpreting the law; without interpretation, no legal proposition can be applied. Structurally, this interpretation of legal wording differs only slightly from the determination of the meaning of other texts. Nevertheless, it is a special case, because it is directed towards the determination of normative meaning. Of course, this is not a unique feature of jurisprudence; theology has a similar objective, and with some exceptions, practical philosophy, too.

In any case, jurisprudence differs from other normative sciences in that the subject matter to be interpreted is associated with a legal claim to validity. It is the task of lawyers to determine what is legally valid in view of the given legal principles. This results in certain limitations of the methods of interpretation and the aims of interpretation, which are determined, among other things, according to whose will, standard, or horizon the norm to be determined must or should be expressed: that of the (original) norm maker or that of the (current) norm user? These considerations hint at deep questions of the legitimacy of law, which are dealt with by legal methodology, legal theory and the philosophy of law.

Detached from these deep material questions, three objectives can be analytically distinguished with which lawyers can approach the interpretation of legal propositions. It can be about:

- finding the only correct interpretation (qualified claim to correctness),
- a correct interpretation (simple correctness claim) or
- exactly one interpretation, whether correct or not (no claim to correctness).

The first variant assumes that the law provides the one right answer to every legal question - the challenge is then to find it. It assumes that this answer can be found in principle; and a supernatural practitioner of law, such as the imagined *Judge Hercules* of U.S. legal philosopher Ronald Dworkin, would even be able to find it. Non-Herculean judges, on the other hand, can always make mistakes, so they can never be sure of having found the one right answer. This uncertain-

Dangers of climate change and the state's duty to protect

"The protection of life and physical integrity under the first sentence of Article 2(2) of the Basic Law includes protection against impairments caused by environmental pollution, regardless of by whom and through what circumstances they are threatened. The state's duty to protect, which follows from Article 2.2 sentence 1 of the Basic Law, also includes the obligation to protect life and health from the dangers of climate change, for example from climate-related extreme weather events such as heat waves, forest and wildfires, hurricanes, heavy rainfall, floods, avalanches, and landslides. It can establish an obligation under objective law to protect, also in relation to future generations. As property, for example agricultural land and real estate, can be damaged as a result of climate change, for example due to rising sea levels or droughts, the fundamental right to property under Article 14 (1) of the Basic Law also includes a duty of the state to protect with regard to the property risks of climate change."

From: „Verfassungsbeschwerden gegen das Klimaschutzgesetz teilweise erfolgreich", Press Release No. 31/2021 of the Federal Constitutional Court of 29 April 2021.

Fig. 2: Building of the Federal Constitutional Court in Karlsruhe (Photo: Guido Radig / wikimedia commons).

Fig. 3: European Court of Justice building in Luxembourg (Photo: Luxofluxo / wikimedia commons).

ty, however, does not result from the under-definition of law, but from the defectiveness of the user of law. Error-proneness instead of correctness.

The second variant recognises that the law may not always have exactly one, but sometimes several answers to a legal question, all of which may in principle be equally legally correct. This relieves the burden on lawyers working in practice. Accordingly, it is sufficient if they justifiably claim to have found a legally correct opinion; they do not have to make the – potentially erroneous and impossible – claim to have determined the only correct answer. But this conception has a significant weakness compared to the first. The claim to have the correct opinion will hardly convince the one who makes the justified claim to have found another, equally right answer. This would open the field for a potentially endless argumentative debate about the choice of the alternative correct law – which ultimately can only be decided qua authority, that of the court of last instance. Authority instead of correctness.

The third variant makes the answer to the weakness of the second variant its leitmotif: there may only be one decision. Admittedly, the mere fact of the pronouncement of a decision by a legal institution competent to do so, such as a court, will not be able to convince those who want not just any decision, but a correct one. Arbitrariness instead of correctness.

Photo: ist.

These variants outline the three essential models of legal, especially judicial, decision-making: the cognitive model, the argumentation model, and the decisional model. There is much to suggest that the argumentation model represents the happy medium. It neither overburdens legal practice to the extent that it has to claim counterfactually to have found the only correct decision on every legal question presented, nor does it allow practice to degenerate into a mere instrument of effective control through power. The argumentation model also has the advantage that it neither exaggerates nor undermines the law's claim to correctness. Of course, the problem of justifiability remains. Why, for example, should a defendant be satisfied with the fact that it is a justifiable, quite correct, but in any case not incorrect interpretation of the applicable law to sentence him to imprisonment – even though an acquittal could have been justifiable with equally good arguments (mind you: on the basis of a different interpretation of the law, not for reasons of epistemic uncertainty, since *in dubio pro reo* applies)?

In order to solve this problem of justifiability, the following approach has been proposed in legal theory, for example by the Frankfurt legal philosopher Ulfrid Neumann.[1] Here, the judge must act as if they have found the only correct solution, so that the authority of the law is not undermined by raising a lesser claim. There is pragmatic wisdom in this; but the proposal remains unsatisfactory because it amounts to deceiving those involved in the court proceedings about the performance of the judge and the law. In practice, therefore, it must suffice for the judge to make the simple claim that his decision is correct. It is only promising to proceed against this if the decision could not only have been different with good reasons, but should have been different. This could be achieved in criminal law by extending the principle *in dubio pro reo* to normative uncertainty.

It is certain that jurisprudence can deal with epistemic and normative uncertainties. It has established procedures for doing so. Uncertainties are unavoidable for lawyers - but they are manageable if the demands on the law and its correctness are not exaggerated.

1 Dazu C. Bäcker: Anspruch und Wirklichkeit des richterlichen Entscheidens: Ulfrid Neumann und die Illusion der einzig richtigen Antwort, in: F. Saliger (ed.): Rechtsstaatliches Strafrecht: Festschrift für Ulfrid Neumann zum 70. Geburtstag. Heidelberg 2017, 43-54.

INTERVIEW WITH PROF. DR. CARSTEN BÄCKER

Christian Wißler

On the rationality of legal reasoning

When you moved from Kiel University to the University of Bayreuth in the summer of 2018, you brought with you a research project funded by the German Research Foundation entitled: "Revising rational beliefs in legal reasoning: Defeasibility, Counterexamples, and probabilities". What is this project about?

This project was embedded in the DFG Priority Programme 1516 "New Frameworks of Rationality", a multidisciplinary undertaking to research rationality from diverse subject perspectives. The participants were primarily philosophers, especially logicians, as well as psychologists and computer scientists. The project you mentioned, which is led by the cognitive psychologist Markus Knauff from Giessen and deals with the rationality of legal deliberation and reasoning, will continue until the end of 2021 for organisational reasons. My task as co-leader was initially primarily to ensure the legal setting of the cognitive psychology experiments. We sought to put the rationality of lawyers to a psychological test - not least from the point of view of what constitutes the rationality of legal reasoning and where it reaches its limits.

Could you give an example of this?

Legal reasoning must follow the laws of logic. An illogical reasoning of a judgement is not only irrational, but also legally flawed. The process of reaching a judgement, however, is not bound to logic in the same way. In fact, insights from cognitive theory suggest that other mechanisms of rationality are at work here. We approached the question of which mechanisms are at work by conducting psychological experiments on the assessment of homicides with advanced law students on the one hand and students of other subjects, i.e. legal laypersons, on the other. All test subjects recognised the rule "criminals must be punished" as such. However, they applied this rule very differently with regard to certain circumstances on which the type and duration of the punishment could be made dependent. In contrast to the legally trained participants, the laypersons were, for example, also prepared to recognise circumstances far outside the course of events – for example, sexual abuse experienced by a third party in childhood – as relevant for punishability. Significant differences were also found with regard to the punishability of offences. Test subjects with previous legal training found homicide, child abuse, and tax evasion indiscriminately worthy of punishment, albeit with different levels of punishment; legal laypersons considered the punishment of tax evaders to be less important. This revealed a result that still concerns me. After only a few semesters of legal education, the moral compass seems to change significantly. I have the impression that the general-social moral compass is quickly overlaid by a legal one in law school. But this needs to be researched further.

What does this imply for the rationality of legal reasoning?

For the rationality of legal decision-making, this means that lawyers are apparently more willing to apply given rules in accordance with the rules, i.e. deductively. They are less likely to question the correctness of legal rules based on moral or other norms; rather, they see themselves as users of the law. This can be reassuring at first, but it also has its dark side – which becomes starkly apparent when the legal system in force has become morally corrupt. This is still discussed in legal philosophy today with regard to the question of whether lawyers should have refused to obey the law during the Nazi era. This question was repeated after 1990 in the Mauerschützen trials (on the shooting of East Germans crossing into West Germany), and it became apparent a few years ago in the case of the registrar Kim Davis in the USA, who refused to perform the legally required marriage of a same-sex couple for moral, or more precisely, religious reasons. In short, the relationship between morality and law is one of the core questions of legal philosophy. Our experiments open up a new perspective on this.

Not least the Covid 19 pandemic and its consequences – from the lockdowns to the debate about compulsory vaccination – have made it clear that there is often an irreconcilable tension between the principles of "freedom" and "security". Have you been able to detect differences between the test subjects in this respect as well?

No, that has not been the subject of our experiments so far. However, we are currently trying to question the rationality of weighing decisions. To this end, an experiment has been developed in which the test subjects – again, advanced law students on the one hand and legal laypersons on the other – are to weigh up specific constellations themselves, using the example of decisions of the Federal Constitutional Court in which fundamental rights positions collide. We then intend to compare the results with the Court's considerations. It will be interesting to see the differences and similarities!

From your point of view, what are the most important, possibly also surprising, insights you have gained in the course of your DFG project?

The biggest surprise for me was the realisation that logic plays a rather subordinate role in everyday human reasoning. This naturally also applies to legal reasoning. However, legal conclusions, unlike other human decisions, must be able to be presented as logical in retrospect. I am convinced that this has an impact on the formation of legal decisions. I expect that we will come to similar results with regard to the weighing of considerations in the application of law. We need a logical justification for this process, similar to the logical structure of subsumption, which can raise it above the frequently voiced accusation of arbitrariness or irrationality. The search for this began in legal theory some time ago; our experiments could bring us somewhat further.

Andreas Kögel

Death is certain, dying is not

A sociological classification of patient's provision

Resuscitation attempt in the emergency room of a hospital (Photo: ist).

Uncertainty is closely interwoven with insecurity. Both are dealt with in sociology under the term "risk". According to this, uncertainty is not a special case; it accompanies every decision as a matter of course. In everyday understanding, the corresponding counter term is security. However, security only exists as a promise, because every side of a decision is risky in its own way. It ultimately remains subjective, as an expectation of security or a feeling of security in the immediate present. Sociological systems theory instead distinguishes between risk and danger.[1] Risks are attributed to the decisions of the subject, whereas dangers come from the subject's environment. One chooses one of several options and risks exposing oneself to greater danger than would have prevailed if one had chosen another option. This affects every area of society – and thus also medicine and health care.

Risks of Medicine in Transition – Controversies about the preservation of life

Risks in medicine have changed, but have remained a self-evident part of medicine. Before the triumph of science-based medicine, going to the doctor or not was equally risky, think of traditional, predominantly harmful practices such as bloodletting for infectious diseases. It was not until the 19th century that the ratios shifted in such a way that it clearly became more risky not to go to the doctor for serious ailments. Today, the advantages of medical treatments outweigh the disadvantages. These include not only rare side effects, but more and more frequently the undesired prolongation or perpetuation of a phase of suffering through medical technology.

A symbol of the possibilities of modern technology in medicine, but also of its downside, is the intensive care unit with its impressive and often frightening equipment. It can temporarily sustain life in a weakened body during a crisis, which is obviously a plus. But it can also delay a death that can no longer be averted, in which case it draws criticism.[2] In everyday perception, dying attached to machines, cables, and tubes is a kind of modern limbo that most people would wish to avoid. However, medical actors tend to err on the side of treatment: They feel legally safer because acting implies more control than not treating, which is perceived as a deliberate, legally problematic waiver of control. The same applies to those affected and their relatives, and so when a crisis occurs, the dying person ends up in hospital after all, and usually dies there. This is not necessarily the worse option, because the expectations of dying at home are often romantically transfigured. Moreover, fears are not centred on temporary admission, but on overtreatment and a longer, final stay. However, the resources available in hospital encourage further treatment, and so it can happen that patients are resuscitated, operated on, ventilated or fed via a PEG tube, even in hopeless situations.

The technical possibilities have advanced so far that people who would have died within minutes a few decades ago can be kept alive for weeks, months, or even years in some cases. Exactly what constitutes a person's life and precisely when they are dead or still alive is a further point of controversy – think of brain death as a death criterion for organ removal for transplantation. Depending on the medical tradition and the value conceptions of the observers, one and the same set of circumstances can be interpreted and evaluated completely differently. What some call life-saving is for others a torturous prolongation of death. There have been many cases of patients in a vegetative state whose fate has been the subject of years of legal dispute between relatives or between relatives and the management of care facilities. Each time, the question has been whether life support should be discontinued or continued.[3]

Fig. 1: Intensive care nursing (Photo: ist).

What are living wills for?

The stabilisation of vital bodily functions with machines is legally a treatment, and can in principle be refused by the persons concerned. However, this option does not apply if the persons concerned are in a state of lacking or diminished capacity to consent

RECOMMENDED READING

Andreas Kögel: Medizin und Gesellschaft. Eine Einführung in die Medizinsoziologie. Stuttgart 2021.

Andreas Kögel: Tod und Sterben als Risiken. Münster 2016.

Gerd Gigerenzer: Risiko. Wie man die richtigen Entscheidungen trifft. München 2013.

Niklas Luhmann: Soziologie des Risikos. Berlin 1991.

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before and during the treatment. Living wills and health care proxies are designed to deal with situations like this.[4] With a living will, one's own autonomy and decision-making capacity is projected into the future – for the case there no longer being any immediate personal decision-making capacity. With a health care proxy, decision-making power is transferred to selected persons, control is relinquished, but at the same time the scope for action is limited. The aim is always to have extensive or at least partial control over one's own future dying. Those who draw up a living will, mentally anticipating their own mental absence, set rules or framework conditions that are intended to ensure that treatment decisions are not made against one's own wishes and interests when this emergency actually occurs.

Therefore, a living will also communicates mistrust towards the decision-making behaviour of others. And this, of all things, towards authorities who basically claim complete trust for themselves: relatives, doctors, lawyers, and clergy. Paradoxically, however, the living will in turn presupposes an overriding trust (system trust), especially in the judiciary – one trusts or at least hopes that it will be respected and enforced. The establishment of the living will through legal regulation in 2009 met with some resistance in the run-up. The main arguments, partly ethical, partly pragmatic, have not changed to this day: one cannot – or should not – anticipate the future; future treatment will be complicated and bureaucratised; the living will is notoriously incomplete and inappropriate because it cannot anticipate all eventualities. However, the objection that the advance directive only conveys an apparent sense of security does not apply: the mere feeling of security improves current quality of life and is thus an added value. Doubts are also frequently expressed that the provisions contained in the disposition will not correspond to the current attitude of the person who drafted it in the event of an emergency. As a rule, this objection does not apply either – because if a person can change his or her attitude in an emergency, he or she is capable of making decisions and can revise his or her disposition.

What should not be forgotten is that a living will can go in any direction. Not only can the complete omission or discontinuation of treatment be demanded, but a preference for preserving life as far as possible can also be formulated. The motives can be very different. Patient A adheres to a Christian mysticism of suffering and might be afraid that non-spiritual relatives or doctors will let them die prematurely. In turn,

atheist B might be afraid of Catholic relatives or doctors who keep delaying the end of life because they do not want to violate the principle of an absolute protection of life in any way and thereby incur guilt. Patient C may fear that he will be given up at the first opportunity for reasons of cost savings or the transplantability of his organs – because an organ donor card is, legally speaking, a kind of living will. Patient D, finally, fears individual close relatives who may not manage to let go and push for life-sustaining measures – supported and confirmed by a hospital department that can earn money by doing so.[5]

The living will fulfils various functions:

- *instrumental:* guidelines for action or decision-making in specific medical situations. Emphasis on one's own preferences at the time of writing the directive. Protection from relatives or hospital staff guided by principles or interests.

- *social relief:* for relatives and clinic staff, taboos are lifted or weakened – "In this or that situation, you may let me die without a guilty conscience". The objection "but we can't let your relative starve/bleed to death" is invalidated. Or, conversely, the affirmation that one absolutely wants to continue living, even if it will only be possible under severe restrictions.

■ Fig. 2: High-tech medicine: checking the data transmitted by a heart-lung bypass machine (Photo: ist).

ing, and in the end, everything will be all right"). In turn, an advance directive can also be perceived as a relief by relatives and parts of the hospital staff – there may always be situations in which a decision is overly difficult for those involved. Clearly formulated preferences avoid processes of clarification under the time pressure of an emergency, and perhaps also disputes with other parties involved.

Decisions despite uncertainty – risky but inevitable

According to the sociology of risk, safety is subjective and observer-dependent. The subject makes a decision and feels safe or not. Someone who observes this person from the outside may reckon differently and criticise their decisions as irrational. But no one has all the information relevant to a decision, and so despite uncertainty, we have to make decisions that can no longer be revised – for example, in choosing educational paths, life partners, financial investments, or tattoos. Security is ultimately the present, reassuring feeling of having made the right decision.

"The aim is always to have extensive or at least partial control over one's own future dying."

In the German health care system, living wills are now an established option. Everyone has to make a decision on this, and it is risky on both sides. Those who decide to write an advance directive risk that it will not fit the situation in an emergency; those who refrain from doing so risk being treated (or not treated) against their interests. And there is always the possibility that one's attitude will change and that one will regret an earlier decision. Even later regret can be anticipated in the present: "If only I had" or "if only I hadn't". Those who see this possibility of later regret as a problem can nevertheless not avoid the decision. Only in a few definable areas of life can one pretend to oneself that one is foregoing a decision in the face of uncertainty and derive a sense of security from this. The living will, however, is no longer one of them.

■ *political communication:* expressions of unease about undesirable developments in the health economy up to concrete mistrust – towards the motives of doctors and relatives or the momentum of organised health care. These fears can be manifold – often it is about economic incentives or medical ambition, in individual cases one can see motives for unnecessary preservation of life or for premature abandonment in equal measure.

■ *worldview positioning:* protection from relatives or hospital staff guided by other moral principles.

Ultimately, the living will is a natural step in empowerment, and its rejection by some – by no means all! – professionals a defensive reaction (psychoanalysis would use the term *narcissistic mortification*). The authors lack confidence that those directly involved will decide in their favour if necessary, or that they will come to an amicable agreement in case of conflict; and hence guidelines or concrete rules are decreed. In principle, even the self-description of the authorities addressed are doubted: medical capacity ("modern palliative medicine can alleviate or even prevent any suffering") and the primacy of the patient's welfare or interests. In the face of clergy or believing relatives, their trust in God or a merciful fate ("Everything has a deeper meaning, even suffer-

Photo: ist.

1 N. Luhmann: Soziologie des Risikos. Berlin 1991.
2 Cf. M. de Ridder: Wie wollen wir sterben? Ein ärztliches Plädoyer für eine neue Sterbekultur in Zeiten der Hochleistungsmedizin. München 2010. Just as critical: M. Thöns: Patient ohne Verfügung. Das Geschäft mit dem Lebensende. München/Berlin 2016.
3 Prominent is the case of Teri Schiavo, similar cases in Germany are cited e.g. in de Ridder 2011 and Thöns 2016 (see n. 2).
4 Any social pressure on the patient in favor of further treatment is ignored here; the living will does not apply here.
5 Cf. the allegations of Thöns (see n. 2).

Eckhard Nagel

Inerrancy and responsibility

On the relationship between politics and science

Above: View of the plenary chamber of the German Bundestag (Photo: Steffen Pröß dorf / wikimedia commons / CC-BY-SA-4.0). Below: Microscopic studies in the context of the Covid 19 pandemic (Photo: ist).

The past months have been marked by a sometimes heated dispute about who should prepare, make, and take responsibility for decisions in view of the uncertainty about the course and significance of the Covid 19 pandemic. This has resulted in close and certainly necessary cooperation between science and politics, which will be remembered figuratively in the regular press conferences held by the Robert Koch Institute in the presence of the Federal Minister of Health. What is problematic about this image is the relationship that exists between the President of the Robert Koch Institute, Professor Lothar Wieler, and member of the executive, Minister Jens Spahn, who is actually the employer and superior of the head of this federal scientific authority. To deduce from this that science is in a position of dependency is not only wrong, but also contradicts our understanding of the freedom of science and research, which is protected by the Basic Law.

With regard to the interplay between science and politics, others may recall that in various media appearances, scientists have made ultimate demands on politicians, postulating that - if these were not implemented quickly - not only would political failure be the result, but many citizens would be in mortal danger. The public uproar has contributed to putting those with political responsibility on the defensive in these situations. Sometimes contradictory political action has been the result, at the cost of a loss of confidence among the general population.

Both pictures make it clear that in the months of the pandemic, the network of relationships between science, public opinion, and politics developed in a very heterogeneous and ambivalent way. At the beginning, the focus was very concentrated on and confident in initial scientific findings that supported efforts to save the lives of seriously ill people in medical institutions. However, this positivistic basic attitude towards science has since then gradually eroded. The same applies to the trust in those with political responsibility and their ability to decide on a comprehensible and consistent course of action based on the respective state of scientific knowledge. The result was a dispute that, especially with regard to science, focused on the question of whether a primarily intellectual approach to the individual and societal problems of the pandemic, based on a great deal of detailed knowledge, might not lead to a better solution to the problem than the prescriptions for action from specialists in the field of politics. Thus, the dispute between opponents and supporters of so-called coronavirus measures became a dispute about the status of science itself, about scientific communication, and the relationship between politics and science.

In this context, Chancellor Angela Merkel allowed us a surprisingly personal insight into her inner compass in December 2020 during the general debate on the 2021 budget in the German Bundestag. She explained her choice of subject:

she had studied physics to gain orientation. In a country where reality was always dependent on its interpretation by the powerful, the study of the laws of nature had represented a decisive inner and substantive positioning for her: the laws of gravity, the principles of the earth's gravitation, and the speed of light could not be reinterpreted.

Fig. 1: German Chancellor Angela Merkel in Dezember 2015 in Karlsruhe (Photo: Olaf Kosinsky / Skillshare.eu / wikimedia commons).

Uncertainty and dwindling confidence

While a close link between scientific knowledge and political action could be deduced from this, many commentators, meanwhile, are taking politics to task: decisions have been made too late, scientific findings have not been interpreted correctly, important time has been wasted. Under the headline "Mit dem Latein am Ende – Die Politik hat fertig" (At the end of the road - politics is finished), a commentary on Deutschlandfunk put it in a nutshell: multiple misjudgements, uncertain action, responsibility for public confusion, and other inadequacies in dealing with the pandemic have characterised recent politics. There were serious gaps between the commitment to trust in science and the actions taken in the political lowlands, which ultimately allowed only one conclusion to be drawn: The recommendations of the National Academy of Sciences Leopoldina on the current infection situation and the resulting conclusions for actions in the public sphere were well-founded and based on clear scientific analyses. Politics had finished and it was time for virologists to take over the reins of government, at least for a certain period of time, so that stringency in actions and calm would return to the country.

In the given situation, such statements might meet with a certain level of public understanding. The so-called third wave of the pandemic was emerging with a large number of new infections, the risk of the virus spreading further within Germany was constantly increasing, and with it the concern grew that this could possibly lead to the need to prioritise treatment measures, especially in intensive care

Fig. 2: Main building of the German Academy of Sciences Leopoldina – National Academy of Sciences in Halle (Saale) (Photo: Gunther Tschuch PaulT / wikimedia commons).

units. For the author of this article, however, this comment not only caused not only an amount of head-shaking, but also some inner resistance.

"The probability of error is a characteristic of science. We must integrate it into our relationship with government if reason is to remain the guiding principle for action."

It is certainly true that since the outbreak of the pandemic, we of the mostly Western, industrialised countries have discussed the importance of science for the development and well-being of our societies with unusual vigour. The direct connection of scientific findings with the protection of life and limb has led to an emotionalization of the debate, the passionate and serious nature of which would seem, at first glance, positive for a scientist. This is because over the past decade, we have seen a clear distrust of scientific findings, especially when they collide with economic or political goals, for example in the case of climate change. The sharp attacks of former U.S. President Donald Trump, who portrayed scientists as un-American and conspiratorial because they had confirmed that the cutting of CO_2 greenhouse emissions was crucial in salvaging a liveable planet, will still resonate in many ears. In doing so, they had contradicted the Trump administration's political and economic goals, and were attacked not just in terms of substance, but also personally, without basis in any other scientific work or findings. Some will also remember the *March for Science*, the worldwide demonstrations for the importance of scientific research. These were the expression of an insecurity that also affected the organisational structures and internal constitution of science, and clearly showed the concern that we humans could say goodbye to what has distinguished us even before the birth of Kant's critical philosophy: the use of reason to shape our living worlds.

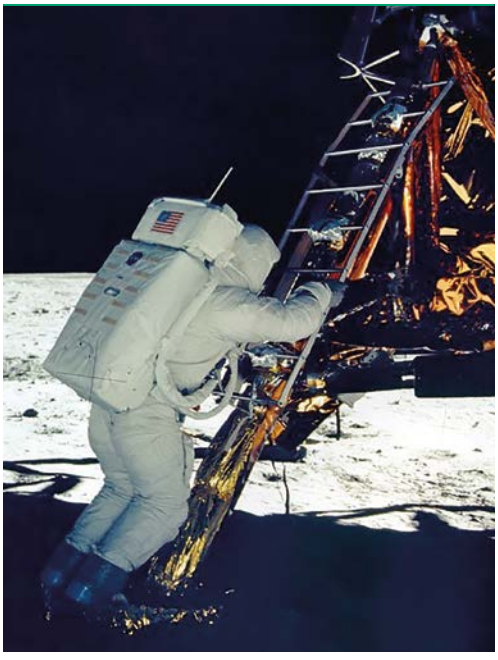
Effective to this day: The Humboldtian ideal of education

This development is all the more irritating because advances in technology and the natural sciences, in the humanities, cultural studies, and social sciences have revolutionised our lives in the past 60 years as never before. Some people may still remember the end of the 1960s. At that time, two events that took place in distant places marked the beginning of a period of scientific positivism that was by no means restricted to venerable university halls, but found its way into the living rooms of millions of people via the then still rather blurred black-and-white images

Fig. 3: March for Science in Berlin in April 2017 (Photo: Heike Mewis / wikimedia commons).

on the television set. These events were the moon landing including Neil Armstrong's small step that became a big one for mankind, and the first heart transplant a year earlier in South Africa. For the first time, both these events were based on scientific developments and thoroughly covered by the media and, and no one could really assess what they might have to do with oneself. Nevertheless, a feeling of motivation spread to the school classrooms. Something had been achieved here that would in principle have a positive influence on everyone.

Some might object that a lot of naivety and even more emotionality went into this perception. By definition, neither have a place in science. But be that as it may, it has not harmed the development of many generations of young people who have set out to pursue school and university degrees to work for the betterment of the world. There was a revival of public enthusiasm for science, of a type that Alexander von Humboldt once knew how to generate. Essential principles of the educational ideal developed by his brother Wilhelm still form the foundation of our communal existence to this day. Demands for freedom, responsibility, and morality, based on the conviction of an unchanging reason, are the starting point of scientific and university thinking. High school graduates like Angela Merkel have internalised this and intuitively or consciously chosen their field of study in this tradition.



■ *Fig. 4: Statue of Immanuel Kant in Kaliningrad, after the original by Christian Daniel Rauch (1777-1857) that was lost in World War II (Photo: wikimedia commons).*

Science and research: free, resilient, and neutral

In these decisions, it is important to understand the position science has not only in public perception but also with regard to the realisation of life plans. This is linked to the question of whether science and art form an unrestricted space that is resistant to external influence, or whether restrictions on thought and action through political reprisal should narrow this space.

Science and art, as the protected spheres as they are in Germany's Basic Law today, have a central position in the organisation of the polity. This central position is based on the confidence that, in order to determine the truth, a serious effort in a methodical, systematic, and verifiable manner will produce findings that are useful and beneficial to all. This expectation refers to the neutrality of science as set out and justified by Max Weber. He assumed that scientific knowledge is objective and thus value-free. Science therefore makes no judgements about the world as it should be, it merely describes the world as it is. Thus, the path to the acquisition of knowledge through science is built on the ground of freedom. This happens in unconditional trust in reason under the postulate of neutrality. Science is largely immune to personal interests and individual desires. This even applies when the original research question

■ *Fig. 5: Portrait of Alexander von Humboldt from 1806 by Friedrich Georg Weitsch (1758-1828) (Photo: Karin März / wikimedia commons).*

■ *Fig. 6: The first moon landing in December 1968: Buzz Aldrin exits the Apollo 11 lander (Photo: NASA / wikimedia commons).*

already has the potential utility of the results in mind, like, for example, in vaccine research or in identifying the epidemiological rules for structuring a pandemic response.

Fig. 7: Max Weber, photograph from 1918 (Photo: wikimedia commons).

Max Weber also admonished science to remain politically neutral. How difficult political neutrality is, for example, for a scientific body advising government, was demonstrated in the last two decades by the establishment of the National and later the German Ethics Council. Heated by the discussion about the moral limits of scientific development, as exemplified by embryonic stem cell research, Chancellor Gerhard Schröder convened a committee in 2001 to highlight ethical developments in the life sciences and present them to wider society in a comprehensible way. The media attention was reduced to the question of whether there were majorities and minorities within the panel with regard to certain positions. It was a long and arduous process to make the public understand that science has to follow rules of neutrality and that a committee, even if it is appointed by the German Federal Government or the German Bundestag, cannot or should not take over its tasks.

In the dialogue between science and government, the task is to compile the scientific arguments for a specific question in their entirety and, if necessary, even in their contradictory nature, to explain them in a comprehensible way and to support government with possible conclusions, which can of course differ if the arguments are weighted differently. Political decisions, for their part, should then follow conscience, and not this knowledge exclusively. This is the basis for the acceptance of majority decisions.

Networking of science and society

In the dialogue between science and society, it is also essential to understand the basic features of scientific methodology, which is often oriented towards experimentation and not infrequently produces results by falsifying approaches. Rarely and only in a few disciplines are there regularities of such unambiguity that they can be called laws of nature and prove themselves time and again as the basis of reliable predictions. Physics is one of these, and Angela Merkel spoke of it. The situation is different in economics and medicine, for example. Here, predictions are continuously corrected and further developed. Many people are familiar with the situation that clinical findings are ambiguous or that proposed therapies do not always lead to success. This is what distinguishes economics and medicine from physics.

In December 2020, we find ourselves once again in the same general debate conducted by the German Bundestag. The arguments presented there have not strengthened confidence in science in either direction. Biology and the medicine based on it are only rudimentarily comparable to physics in principle. That is why the study of human medicine could not have provided orientation for Angela Merkel, a high school graduate, as she had hoped physics would. And that is why recommendations from excellent scientists from various disciplines are not laws of nature on which political action can be calculated stringently and with great certainty in planning. It therefore becomes problematic when scientific committees recommend concrete action that requires a genuine political justification. Accordingly, it is a fallacy to believe that a committee of experts can make better decisions than the elected and responsible politicians. This form of understanding science endangers the progress that selective knowledge can contribute to supporting political decision-making. Above all, science and politics alike are caught in a dilemma of justification, which is accompanied by a loss of public trust. Medicine is not physics. A pandemic does not behave according to laws of nature that we can grasp.

Fig. 8: View inside the copula of the Reichstag building in Berlin (Photo: bluejayphoto / istockphoto.com).

The unanswered questions regarding the phenomenon that has been with us since the beginning of 2020 still loom large. Science can help to clarify these questions piece by piece and slowly generate an overall picture with each answer, like a puzzle. In the meantime, the knowledge we have already gained helps us secure and maintain our lives with new rules that need to be defined. These rules are naturally changing constantly, because our gain in knowledge makes this possible. Only if the resulting uncertainty and the range of unanswered questions are not understood as a loss of authority but as a natural framework of human action, can their communication help to calm the uncertainty of society as a whole. The probability of error is a characteristic of science. We must integrate it into our relationship with government if reason is to remain the guiding principle for action.

The Chancellor's contribution to the general debate of the Bundestag can and should therefore be understood as a plea for the ethical and political neutrality of science. On the other hand, anyone who understands this contribution as a rationale for the subordination of political options for action to rational findings, which are inevitably subject to a high degree of volatility when the object of investigation – as in the case of the coronavirus pandemic – is endowed with many unknowns, is encouraging misinterpretation that in the end damages both democracy and science.

Conclusion

The lasting management of the pandemic depends on many factors, and outstanding multidisciplinary scientific expertise is needed to answer current questions. It requires a differentiated perception of this expertise on the part of politicians, who can derive comprehensible and stringent recommendations for action from it. This will enable a solution to the overall problem in which each and every individual assumes responsibility under the given framework conditions. Only if it is possible to create a collective willingness to act – and this is also a task of the media, which accompany both science and politics – can overarching challenges be overcome.

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Characteristic and ambiguous

For two decades, they have enlivened the campus of the University of Bayreuth: the colorful free-standing bronze sculptures of Stephan Balkenhol, one of the most important contemporary German sculptors. With exhibitions in leading museums and galleries, the artist, born in Fritzlar in 1957, has earned a high reputation at home and abroad. His characteristic sculptures, present in many public places in Europe, are not in any single sculptural tradition, nor do they portray historical figures. Rather, they depict generally human figures with individual charisma that deliberately allow for many possible interpretations. "My sculptures do not tell stories. Something mysterious is hidden in them. It is not my task to reveal it, but that of the viewer to discover it," says the artist about his pictural works.