Reliable communication on advanced materials - the impact of science communication on society

Katja Nau[1], Harald F. Krug[2], Clarissa Marquardt[1,5], Andreas Mattern[3], Nadja Möller[4], Christoph Steinbach[4], Dana Kühnel[3]

[1] Institute for Automation and Applied Informatics (IAI), Karlsruhe Institute of Technology (KIT), Hermann-von-Helmholtz-Platz 1, 76344 Eggenstein-Leopoldshafen, Germany
[2] NanoCASE GmbH, NanoCASE GmbH, Breitschachenstr. 12A, 9032 Engelburg, Switzerland
[3] Department Bioanalytical Ecotoxicology (BIOTOX), Helmholtz Centre for Environmental Research (UFZ), Permoserstraße 15, 04318 Leipzig, Germany
[4] Society for Chemical Engineering and Biotechnology (DECHEMA), Theodor-Heuss-Allee 25, 60486 Frankfurt am Main, Germany
[5] Smateso GmbH, Wendelinusstr. 39, 76646 Bruchsal, Germany

katja.nau@kit.edu

Abstract. In times of social change, science has a special responsibility to provide evidence-based results to foster the generation of solutions for the pressing challenges of today, such as climate change or digitalization. To spread knowledge on scientific findings, science communication is inevitable. It intensifies the dialog with the public, objectifies current debates and provides information about the challenges and opportunities of new scientific developments. For more than 20 years, research has been ongoing worldwide on the safety and risks of nanomaterials. In this paper, the authors describe their experiences with science communication, using the knowledge database *www.nanoobjects.info* as an example. Already in 2009, the online knowledge base *www.nanoobjects.info* was established to share scientific results on the safety of nanomaterials with the public in a value-neutral manner. In 2020, advanced materials were added to this information platform to provide understanding and awareness of toxicological data on these materials as early as possible. This knowledge base materials is currently providing safety-relevant information on 30 advanced materials, including nanomaterials, with regards to human health and environmental impact.

Keywords: science communication, advanced materials engineering

1 Introduction

In recent years, the internet and social media platforms have increasingly become the general source of information for the public. There are more and more information portals, also covering scientific topics. Since toxicological effects of advanced materials, such as nanomaterials, on human health or the environment have been investigated, corresponding scientific publications are often followed by

misinterpretations or even misrepresentations of the results in newspapers, social media or online news. However, the lines between facts and fakes are becoming increasingly blurred in news, stories and reports. Information is not always scientifically sound and correctly presented [1]. In addition, scientific publications or scientific studies are not immune to misrepresenting facts, e.g., in the field of medicine or toxicology, mainly due to poor diligence in the execution of tests or data evaluations. In 2012, for example, it was shown that only 11% of medical studies dealing with cancer drug development were reproducible [2]. A similar trend could be observed for studies on the toxicology of nanomaterials or advanced materials [3], and the scientific community reported various problems [4].

This makes it all the more important for scientists to engage in scientific communication and present their research results in a comprehensible and accessible way. Here, in turn, the internet can play a major role. If facts are presented by scientists, citizens gain trust and feel well informed (personal information).

Besides quality issues, science communication itself is facing multiple challenges today, e.g., with the management of the COVID-19 pandemic as one of the most prominent current examples. Typically, scientists communicate their results via scientific publications and conferences to the scientific community and interested parties. However, other stakeholders like consumers, journalists or Non-Governmental Organisations (NGOs) have limited access to these means, but at the same time an interest in impartial information on relevant topics, such as nanomaterial's safety.

This paper provides insights into the work of communicating scientists in the field of nanotechnology and materials safety research. It describes the establishment and ongoing advancement of a web-based Knowledge Base Materials with peer-reviewed scientific publications as its major information source. Based on these experiences and lessons learnt from about 15 years of science communication, the authors implemented specific measures into their science communication strategy to circumvent interpretation bias and to facilitate an informed public debate on materials safety [5], [6], [7], [8]. In the following, the motivation and implementation of these measures `multidisciplinary´, ´data quality assessment´ and ´structured operating instructions´ are presented in detail, and complemented with their advantages for science and risk communication on advanced materials [9], [10].

2 Methods

Early on in the development of nanotechnology and its applications, it became apparent that there is a need for trustworthy, fact-based and easy understandable information from the perspective of multiple stakeholder groups. In order to provide a broader group of interested citizens with trustworthy, expert-curated information on this topic, a public website was established in 2009 in the context of a German research project to communicate data and knowledge on advanced and nanomaterials: www.nanoobjects.info (in German: www.nanopartikel.info) [11].

The goal of the platform www.nanoobjects.info is to provide transparent, reliable, scientifically correct, but easy to understand information on advanced

materials, including nanomaterials. For this purpose, complex toxicological and material science information is collected, evaluated and summarized in a simplified format. The presentation of the content on the webpages follows a uniform format and provides links to further literature for journalists, NGOs and policy makers as well as scientists. The following principles and approaches were applied and further developed for the websites' content creation and science communication on nanomaterials and recently expanded towards advanced materials.

2.1 Principles

Principle 1: Multidisciplinary

Due to the interdisciplinary nature of (nano)material science, it was essential to combine the knowledge from different relevant scientific disciplines for the purpose of truthful communication. This is reflected in the set-up of the multidisciplinary expert team consisting of scientists with backgrounds in human and environmental toxicology, biology, chemistry and material science. These experts are jointly creating content on selected materials or material classes to provide a full picture of a materials' properties, applications and resulting effects on humans and the environment. In addition, all articles are proofread by non-scientists before publication on the website to evaluate comprehensibility. This is to better address the target groups consumers, journalists, NGOs and policy makers.

Principle 2: Literature Quality management

As already described e.g., in [9] peer-reviewed publications in the field of nanotechnology and related safety studies are heavily affected by a number of quality issues making it necessary to conduct a pre-screening process to ensure the reliability of scientific outcomes for further processing and communication purposes. The multidisciplinary expert team behind the knowledge base www.nanoobjects.info therefore developed a study quality criteria checklist that supports the selection of appropriate and reliable studies for communication on material safety as described before [12], [12, 13]. The experiments and study results from toxicological publications (human toxicology and ecotoxicology), are carefully assessed for the categories material characterization, sample preparation, biological test system description, and general quality parameters such as the usage of standardized test protocols (ISO, OECD). To this end, EU and worldwide guidelines are also constantly monitored, checked for relevance and adjustments are made to the catalogue. The catalogue of criteria is public and can be downloaded directly from the website www.nanoobjects.info. This makes the evaluation process transparent and comprehensible.

This initial catalogue of criteria for assessing toxicological publications, acknowledged worldwide in the scientific community, has since been picked up by a number of related projects and has also been further developed to support, for example, the detailed risk assessment of nanomaterials (e.g., GuideNano [14], nanoGRAVUR [15] or for the quality assessment of nanoplastics and microplastics ecotoxicity studies {Kokalj, 2021 #62].

For the articles, only papers that meet the criteria catalogue are cited. Due to the large number of available publications on toxicology of nano and advanced materials a complete mapping of the relevant literature is not possible. Rather, a selection of representative, informative studies is usually used for the articles and listed on the website below the various basic or cross-cutting articles or in the sub-category Literature (Materials). However, all evaluated scientific papers are recorded in an internal library and contribute to the traceability of the whole process.

In addition, this publicly available criteria checklist supports the fair, comprehensible and transparent re-use of data for science communication and knowledge transfer.

Principle 3 Knowledge Base Materials structured writing approach
The approach has already been described in detail in 2022 [13].

Principle 4 Operating Instructions.
With the help of standard operating procedures (SOPs), researchers aim to establish protocols that facilitate repeatability and reproducibility of the individual experiments which in turn can be used for harmonization of methods across a large group of organizations, for example between different international research projects.

The expert team supports the scientific community in a two-way manner, offering a re-usable template on the one hand for the SOP creation for download as well as a repository of already established lab protocols and validated SOPs**.** Publishing SOPs and lab protocols in a downloadable format is intended to support transparency and traceability in research on materials safety.

3 Results and Discussion

3.1 Materials knowledge base

Over the years, with the structured article writing approach using the literature criteria checklist the multidisciplinary team published detailed information on about 30 different (nano)materials.

In addition, the application material database presents more than 150 material-specific applications. In this section, especially consumers will find brief information on (nano)materials and their applications.

Approximately 2.500 scientific papers have been evaluated so far (status Dec 2022). The first material described in detail in the knowledge base materials has been nanoscale titanium dioxide (TiO_2) in 2009/2010. The texts for each material are regularly checked for actuality and if needed, supplemented or adapted with relevant information. Again, TiO_2 serves here as a good example in particular related to its applications in the food sector or other applications such as paint. The gained knowledge on the mechanisms and hazard potential for the different forms of nanoscale titanium dioxide were the reasons behind the re-evaluation process of this material during the last 4 to 5 years. In 2021, this resulted in a change in classification of TiO_2 in certain powder forms as a category 2 carcinogen by inhalation in the EU, the ban of

TiO_2 as a food additive in 2022 followed by the most recent judgement of the Court of Justice of the European Union (ECJ) annulling the European commissions' classification of TiO_2 as carcinogenic in its powder form [16]. The knowledge base articles for TiO_2 were therefore updated as quickly as possible and a major update based on the latest scientific discussions [17], [18] is planned for 2023. Figure 1 shows a screenshot of the website with a selection of materials.

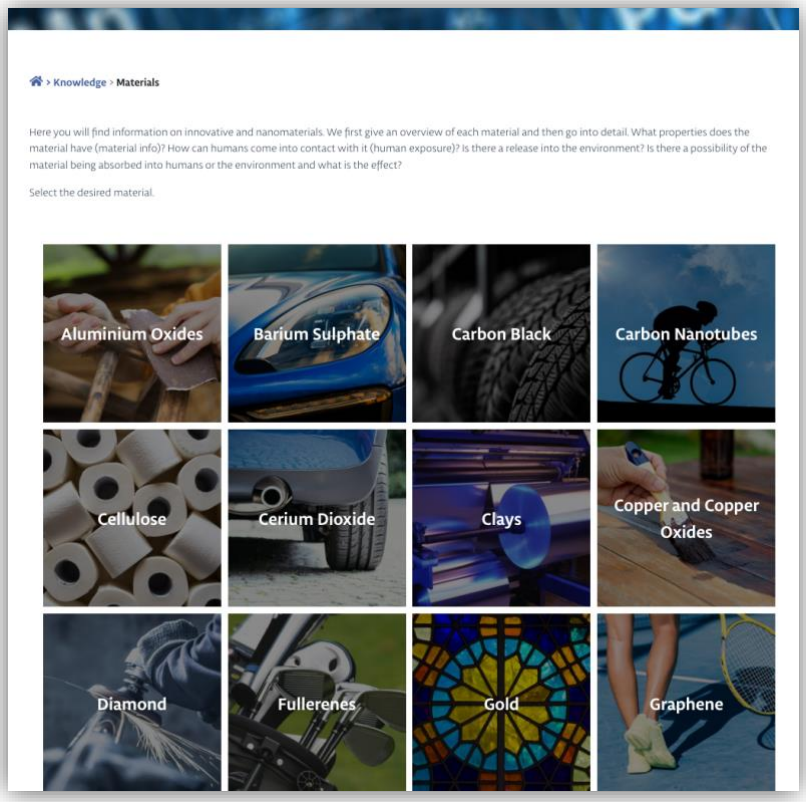


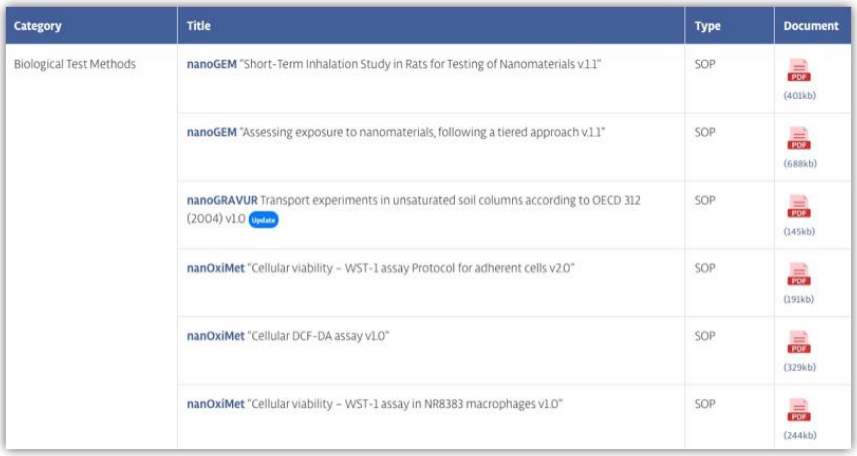
Fig. 1. Screenshot of a section of the materials section of the website nanoobjects.info

3.2 Need for Operating Instructions.

History of publications especially in the field of nanotoxicology has clearly demonstrated that many of these publications contain false-positive or false-negative results based on methodological pitfalls and errors. In general, Standard Operating Procedures (SOPs) describe the exact procedure within a process. Frequently recurring work processes are described in text form and explained to the persons carrying out the work. An SOP includes a unique identification, a validity date or period, a version number, and the names of the creator, auditor and the deallocating person with the respective signatures. It should be clear who specified what and when thereby ensuring traceability at all times.

The repository provided on the website encompasses a collection of SOPs and also laboratory protocols generated in projects from the German BMBF sponsorship program as well as from other European research projects that are not necessarily validated by a 2nd party and do not comply with SOP requirements. The available list of comprehensive protocols is sorted into different categories according to their application areas such as “Biological Test Methods”, “Physico-Chemical Properties”, “Sample Preparation”. Figure 2 shows a screenshot of a section of this list on the website.

The SOP-template was generated on the basis of careful scientific practice and adjusted for (nano)material-specific application areas. Having such a template ready-to-use available for download on the project website encourages other to use it for the establishment of their own SOPs and makes it easy to translate best practices for a method into a clearly communicated, systematically written document.



Category	Title	Type	Document
Biological Test Methods	**nanoGEM** "Short-Term Inhalation Study in Rats for Testing of Nanomaterials v.1.1"	SOP	PDF (401kb)
	nanoGEM "Assessing exposure to nanomaterials, following a tiered approach v.1.1"	SOP	PDF (688kb)
	nanoGRAVUR Transport experiments in unsaturated soil columns according to OECD 312 (2004) v1.0 Update	SOP	PDF (145kb)
	nanOxiMet "Cellular viability – WST-1 assay Protocol for adherent cells v2.0"	SOP	PDF (191kb)
	nanOxiMet "Cellular DCF-DA assay v1.0"	SOP	PDF (329kb)
	nanOxiMet "Cellular viability – WST-1 assay in NR8383 macrophages v1.0"	SOP	PDF (244kb)

Fig. 2. Screenshot www.nanoobjects.info: knowledge/operating-instructions/ Continuously updated list of standard operating procedures and non-validated laboratory protocols from national and European research projects of different categories: biological test methods, physicochemical properties, sample preparation

3.3 Spotlight Research

A 2020 established aspect of the nanoobjects.info website for communicating recent scientific facts and figures is the monthly published “Spotlight Research”. This section is primarily aimed at the science community. For this section, the DaNa team selects relevant scientific papers that convey novel findings in the field of (nano)materials safety research, toxicology, regulatory issues, or on research strategies of other research projects with a view beyond the horizon. The content of the selected publication is described in a condensed way with a specific focus on its novelty and also simplified

so that it appeals to both researchers and interested citizens. A link to the full original paper gives the reader the opportunity to read it in detail. Such short articles showcasing current research outputs can also easily be used for broader communication means via existing social media channels (Twitter or LinkedIn). Figure 3 shows a screenshot of section “Spotlight research”.

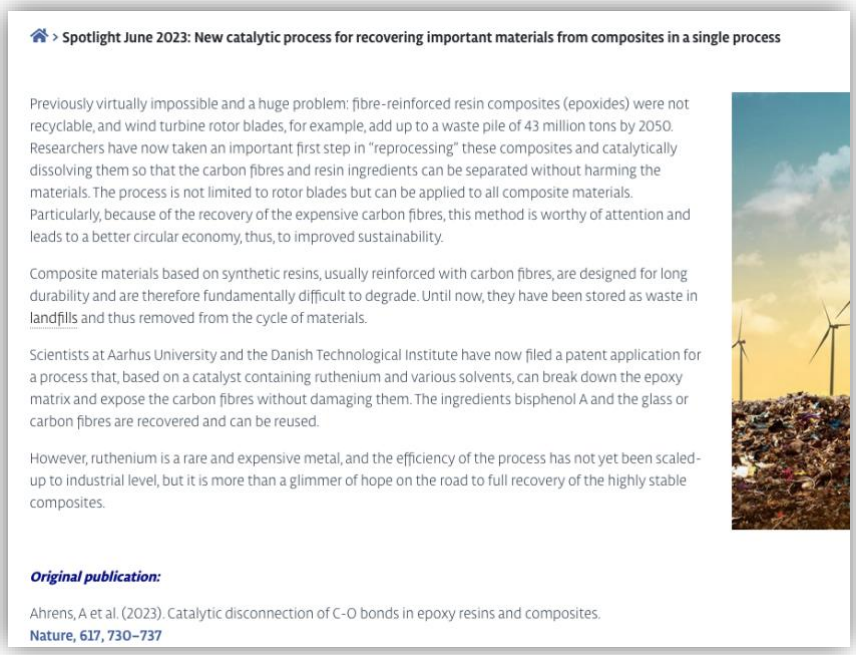


Fig. 3. Screenshot of the website of the Spotlight June 2023.

4 Conclusions

Material research is an important pillar for mankind to cope with the challenges of our time, such as climate change or digitalisation. Science, in this case materials science and toxicology, has a special responsibility to provide evidence-based and reliable findings. This responsibility also encompasses the major task of science communication, generating increasing dialogue activities with the public, objectifying current debates and educating about the challenges and opportunities of novel scientific developments in material sciences. Both funding agencies and EU policy put currently big emphasis on the importance of science communication [19], [20]. The German Ministry of Education and Research considers transparent communication about science, its working methods and positions to be an important prerequisite for better

understanding in society[21]. To become an integral part of the science system, it is necessary for science communication to be driven directly by scientists. In addition to sharing scientific results, the processes and methods used to achieve those results must also be communicated with the public. This can help creating more transparency and increasing confidence in the scientific community. To initiate this change in science, for example, the German "#FactoryWisskomm" was launched. In this think-tank exchange platform, representatives from politics, science communication and science journalism have established working groups to develop recommendations and strategic steps for science communication [22]. These cover e.g., science journalism in the digital age, public engagement formats for science communication or quality assessment & quality management in science communication.

As illustrated in this paper, the concept behind this expert-generated web-based knowledge base materials (www.nanoobjects.info) has already picked up important aspects of science communication related to the topic of nanotechnology and potential issues of nanomaterials for humans and the environment. This fact-based and objective approach generated by the authors has proven to be a successful information source with easy online access for different stakeholder groups based on a transparent process for generating quality-assured information on the safety of nanomaterials and advanced materials. This processing of scientific findings is also transferrable to the novel developments in material science and the authors are currently working on generation of new content for novel classes of advanced materials, for example novel batteries for more efficient storage of renewable energies. As with any scientific field, the process is constantly monitored and adjusted accordingly upon recent updates from the scientific community.

Approx. 97,460 website visitors and 166,000 page views in 2022 show that there is a need for information on the security and applications of materials (internal project analysis according to data protection guidelines).

Taken together, the overall science communication activities have strongly contributed to the science and risk communication for nano- and advanced materials as part of risk assessment, thus promoting a sustainable and responsible use of these materials.

Funding:
This work is funded by the Federal Ministry of Education and Research (DaNa4.0 Information on the safety of new, innovative materials and nanomaterials, FKZ 03XP0282).

Acknowledgments:
The authors would like to thank the former DaNa team members for their contributions to the www.nanoobjects website.

Conflicts of Interest:
HFK is shareholder of NanoCASE GmbH. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

References

1. Salminen, J., et al., *Topic-driven toxicity: Exploring the relationship between online toxicity and news topics.* PLoS One, 2020. **15**(2): p. e0228723.
2. Begley, C.G. and L.M. Ellis, *Drug development: Raise standards for preclinical cancer research.* Nature, 2012. **483**(7391): p. 531-3.
3. Hristozov, D.R., et al., *Risk assessment of engineered nanomaterials: a review of available data and approaches from a regulatory perspective.* Nanotoxicology, 2012. **6**(8): p. 880-98.
4. Oostingh, G.J., et al., *Problems and challenges in the development and validation of human cell-based assays to determine nanoparticle-induced immunomodulatory effects.* Part Fibre Toxicol, 2011. **8**(1): p. 8.
5. Valsami-Jones, E., F.R. Cassee, and A. Falk, *From small to clever: What does the future hold for the safety and sustainability of advanced materials?* Nano Today, 2022. **42**.
6. Marquardt, C., et al., *Latest research results on the effects of nanomaterials on humans and the environment: DaNa – Knowledge Base Nanomaterials.* Journal of Physics: Conference Series, 2013. **429**: p. 012060.
7. Kuhnel, D., et al., *Environmental benefits and concerns on safety: communicating latest results on nanotechnology safety research-the project DaNa(2.0).* Environ Sci Pollut Res Int, 2017. **24**(12): p. 11120-11125.
8. Krug, H.F., et al., *The DaNa(2.0) Knowledge Base Nanomaterials-An Important Measure Accompanying Nanomaterials Development.* Nanomaterials (Basel), 2018. **8**(4): p. 204.
9. Krug, H.F., *Nanosafety research--are we on the right track?* Angew Chem Int Ed Engl, 2014. **53**(46): p. 12304-19.
10. Krug, H.F., *The uncertainty with nanosafety: Validity and reliability of published data.* Colloids Surf B Biointerfaces, 2018. **172**: p. 113-117.
11. Partners, N.P., *NanoCare*
Health related Aspects of Nanomaterials ed. I. T.A.J. Kuhlbusch, Duisburg, Germany , E. H.F. Krug, St. Gallen, Switzerland , and F.K. K. Nau, Germany 2009: Dechema.
12. Nau, K., et al., *The Dana(2.0) Knowledge Base on Nanomaterials - Communicating Current Nanosafety Research Based on Evaluated Literature Data.* Journal of Materials Education, 2016. **38**(3-4): p. 93-108.
13. Nau, K., et al. *Knowledge Base Materials Sustainable Science Communication on Advanced Materials*. 2023. Singapore: Springer Nature Singapore.
14. Fernández-Cruz, M.L., et al., *Quality evaluation of human and environmental toxicity studies performed with nanomaterials – the GUIDEnano approach.* Environmental Science: Nano, 2018. **5**(2): p. 381-397.
15. Wohlleben, W., et al., *The nanoGRAVUR framework to group (nano)materials for their occupational, consumer, environmental risks based on a harmonized set of material properties, applied to 34 case studies.* Nanoscale, 2019. **11**(38): p. 17637-17654.

16. Judgment of the General Court in Joined Cases T-279/20, T.-a.T.-C.P.C. and a.O.v. Commission, *The General Court annuls the Commission Delegated Regulation of 2019 in so far as it concerns the harmonised classification and labelling of titanium dioxide as a carcinogenic substance by inhalation in certain powder forms*. 2022, Communications Directorate Press and Information Unit: Court of justice of the European Union.
17. Driscoll, K.E., *Review of Lung Particle Overload, Rat Lung Cancer, and the Conclusions of the Edinburgh Expert Panel-It's Time to Revisit Cancer Hazard Classifications for Titanium Dioxide and Carbon Black.* Front Public Health, 2022. **10**: p. 907318.
18. Kirkland, D., et al., *A weight of evidence review of the genotoxicity of titanium dioxide (TiO(2)).* Regul Toxicol Pharmacol, 2022. **136**: p. 105263.
19. Agency, E.R.E., *Towards clearer and more accessible science communication*. 2022.
20. Safford, H. and A. Brown, *Communicating science to policymakers: six strategies for success.* Nature, 2019. **572**(7771): p. 681-682.
21. (BMBF), B.f.B.u.F., *Grundsatzpapier des Bundesministeriums für Bildung und Forschung zur Wissenschaftskommunikation*, B.f.B.u.F. (BMBF), Editor. 2019, BMBF.
22. Forschung, B.f.B.u., *FactoryWisskomm, Handlungsperspektiven für die Wissenschaftskommunikation, Berlin 2021*. 2022.