Envisioning and visualizing nanotechnology in the European Union

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Abstract

The European Union has funded numerous scientific projects under its Framework Programmes for Research and Technological Development. Among the scientific disciplines receiving funding is nanotechnology, a field which dates back to as early as the 1960s. Regardless, nanotechnology is considered a pioneering area of research, whose life-changing applications are thought to be close to realization. The report Nanotechnology: the invisible giant tackling Europe's future challenges *published by the European Union provides a list of nanotechnology projects funded in recent years, especially via FP7 '[...] that are representative of the major research themes' in an attempt to shape the European vision on nanotechnology research. The scope of the current work is to study the use of the visual elements in the aforementioned document and their success in the creation of such a vision of nanotechnology. Observations will be used to classify the document under study based on a proposed typology of nanotechnology images in media. Verbal elements of the document will be grouped in isotopies and facilitate a comparison with the narrative used by the visual elements. Results will provide useful insight into the discourse of nanotechnology communication and promotion of science breakthroughs in general.*

Keywords

nanotechnology, epistemology, European Union, scientific visualizations

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Introduction

The results of scientific research have always been in need of efficient diffusion in order to become useful and turn into real life applications. In fact, the more advanced and complicated the underlying principles, the more effort has to be put into their communication. According to Chen and Hicks, 'Knowledge diffusion can be defined as the adaptations and applications of knowledge documented in scientific publications and patents' (2004: 199). As a result, diffusion of scientific knowledge is expected to be subject to all problems typical in adaptations.

Nanotechnology is no exception. It is an interdisciplinary domain which shares common ground with physics, chemistry, engineering and medicine among others and whose field of interest is the control of matter on atomic scale. Such precision spurs promises of innovative and exotic solutions to many problems of the modern world. Its gradual evolution has led to the emergence of a first tier of nanotechnology products, whose new and unfamiliar properties require proper popularization. Of course, the same can be said for every other cutting edge technology, like artificial intelligence, 3D printing, the Internet of Things, Virtual and Augmented Reality, biotechnology.

The characteristics and limitations of texts surrounding nanotechnology accomplishments have been studied in the literature, with researchers expressing epistemological concerns about the use of images, as well as the verbal narratives employed. It is not uncommon to come across terms like "hype" and "speculation" in those studies. The scale nanotechnology takes place is one billionth of a meter, a scale totally inaccessible by human senses. With our perception blocked by physical obstacles, it is only natural that concerns were expressed about the knowledge provided by lab research, concerns which also extend to the achievements promised. Of course, different kinds of texts have different purposes and target audiences so they are bound to have different characteristics and structure. Subsequently, expectations from various media should be adjusted accordingly.

The current paper is organized into two parts. The first part summarizes the different kinds of texts about nanotechnology found in the literature and provides a typology based on the use of images in them. This typology classifies nanotechnology media in a semiotic square based on their connection to actual or speculated objects and their purpose. It can be used to provide critical insight into the production mechanism of similar media and the intended results.

The second part focuses on a specific document issued by the European Union detailing the status of various nanotechnology projects which received funding. It also contains a fairly optimistic description of the future in an effort to present the European vision on nanotechnology. The proposed typology will be applied in order to highlight the standing of this particular document among other texts. Furthermore, a comparison be-

tween the use of the images within it and the verbal narratives will be drawn. Agreement (or lack thereof) will help evaluate the communication strategy of the document in total and highlight the issues presented in the first part of the study.

Nanotechnology texts in literature

Nanotechnology accomplishments originate in the lab. So it comes as no surprise that scientific papers are the first kind of text that have to deal with the communication of nanotechnology. Technically, a scientific paper consists of both written text and images. There is a great amount of research found in the literature focusing on the use of images in nanotechnology, mostly because of the epistemological issues related to pictures in science. Whenever the use of verbal language is studied, it is usually to comment on the ethics[1] of the narratives employed and not so much on syntax. What follows is an attempt to summarize the key points of the related discourse taking place.

Mößner deals extensively with the use of visual representations in scientific media and their epistemic value in contrast to other representational means, especially linguistic expressions (2018). She concludes that '[...] scientific images can contribute to scientific arguments and yield propositional knowledge' (2018: 218) and also that '[...] at least some visual representations in certain contexts can facilitate epistemic achievements that are not attainable via other representational means'; though she also acknowledges that 'Visual representations and also other vehicles of communication are subjected to certain constraints when realizing their epistemic effectiveness' (2018: 327). Dondero and Fontanille point out that scientific images cannot be approached as neutral objects of interpretation but in order to be successfully understood, the relations between elements that led to the creation of the image have to be taken into account, in their words '[...] the entire chain leading from reception to interpretation' (2014: 10). Allamel-Raffin reaches similar conclusions when researching the shop-talk taking place between researchers talking about images of nanospecimens taken with the help of microscopy (2011). She notes that giving meaning to a specific image is governed by four factors: *deep-rooted encyclopaedic knowledge*, *experimental background knowledge*, *knowledge about the sample under study* and the researcher's *expectations* (2011: 171). In other words, the information extracted from a scientific image is greatly influenced by context. Another factor that is crucial in the meaning making process of scientific images is its purpose. Birkeland and Strand argue that 'One can therefore not discuss the status of images without also looking at how images are used' (2009: 187). Dondero and Fontanille make a distinction in purpose between images used as *representational tools* aimed mostly at the popularization of science and as *experimental tools* which are part of the scientific endeavor (2014: 8). Robinson proposes a typology for the various kinds of images found in scientific texts: *Schematics*, *Documentation*, *Fantasy* and *Fine Art* (2004: 167-168). Schematics refer to abstract geometrical representations of numerical data,

documentation involves attempts to visually represent an actual object or phenomenon, fantasy refers to all forms of 'illustrative speculation' like digitally created artistic representations. Finally, fine art (which the author admits is almost non-existent) includes images that seek '[...] some form of meaningful and long-term effect on culture' (2004: 167-168). Clearly, images which serve different functions are not only created through different processes but also perceived in a different manner by viewers.

Consequently, the debate about the use of images in scientific discourse has not led to a definite solution but rather to a compromise. On the one hand, visual stimuli can be very useful in helping us understand complex ideas and can therefore be used efficiently in areas such as education. Xie and Lee research the use of simulations either in teaching or as virtual experiments for college students. They found that '[...] college students gained deeper understanding of abstruse quantum ideas' from the use of simulations (2012: 1017). On the other hand, researchers have expressed their concern about the effects of a non-responsible use of pictures. Bontems explains that scientific images within the scientific field are created and used in specific manner but when they exit this scientific 'life cycle' and enter the mass media, they act as bearers of a ' "halo" about "nano" ', a fact that raises ethical issues (2011: 176). Ottino summarizes these concerns pretty straightforwardly:

> [...] scientists publishing figures as part of their papers should always ask some general questions. What is the point of the image? Is the objective to teach, to excite or to show how things could be? How can this objective, whatever it might be, be made clear to the viewer? There are many new tools for making beautiful drawings, but if good use is to be made of them, scientists and artists should collaborate closely (2003: 476).

Not all nanotechnology texts are made for knowledge diffusion. Art and fiction are usually concerned with aesthetic pleasure. It was previously mentioned that there are already various artistic representations and digital visualizations of nano-objects. However, nano-art can also be of a different kind: a macroscopic artifact whose production would be impossible without the use of nanotechnology. Nielsen discusses some works from artist Gerhard Richter who created them using images from scientific papers captured through scanning tunneling microscopy[2] techniques (2008: 486). Nielsen concludes that 'Relating nanotech to his epistemology of blur and to terrorism and war, Richter's artistic appropriation of nanotech produces conflicting intellectual and emotional responses to this technology' (2008: 491). Kaminska expresses excitement about the use of nanotechnology in media art when she describes the process of production of the cover for the periodical *PUBLIC* (2015). The design team collaborated with a team of scientists in order to produce a nano-film which would be superimposed upon the rest of the printed

cover to produce a novel visual result. The endeavor proved challenging due to the sensitivity of the nano-film but Kaminska believes that 'The possibilities for nano-media are vast, and if we give artists and humanists access to these technologies, we might start seeing things very differently' (2015: 7). Loeve is not so optimistic and is concerned with the artists' limited access to nanotechnology materials and methods for artistic creation (2018: 18):

> Instead of engaging with the nanoworld, designers work only on the symbolic, metaphoric and societal dimensions of future applications and potential uses of nanotechnology, disconnected from its present mode of existence, whose material and operative dimensions are kept out of reach of designers, let to scientists. The intervention of design remains external to the design of the nanoworld. As a result, users are connected to the nano-dimension only by the halo of promises and fears symbolizing 'the future'.

He also expresses his concern about a situation he describes as paradoxical: nanotechnology features either *objects with speculative uses* or *uses with speculative objects*, leading him to conclude that '[...] "object" and "use" remain mutually exclusive' (2018: 4). As far as works of fiction are concerned, *Engines of Creation* by Eric Drexler seems to have gathered most of the attention and critique. First published in 1986[3], the book provides the author's vision of a future where nanotechnology has advanced immensely and changed the course of everyday life. Generalizing to include other similar works, researchers have found an interesting interaction: nanotechnology science fiction is developed along with nanotechnology itself. López remarks that the relation between science fiction, nanoscience and technology is not external but internal; science fiction can bridge the gap between the present and the future and spark discourse in ways nanoscience still is not able to because of the distance between its current development and its promises (2004: 45). Milburn goes a step further and proposes that '[...] nanotechnology illustrates the hyperreal disappearance of the divide between science and science fiction' and that '[...] when they are used to argue the cultural status of nanotechnology, real science and science fiction are nearly emptied of referential pretensions, becoming signifiers of unstable signifieds as they are forced into preestablished symbolic positions of "the real" and "the simulacrum" ' (2002: 268).

Of all kinds of texts, advertisements have been explored the least. This is by no means a surprise as despite all the discourse taking place, actual nanotechnology products are anything but abundant[4]. Campbell, Deane and Murphy have studied the sounds employed in nanotechnology advertisements and found patterns related to whether the target audience was viewers knowledgeable in nanotechnology or not (2017). Different uses of sound were classified depending on the feelings they produced on a spectrum ranging

from 'familiar' to 'strange'. Advertisements created for greater audiences fell closer to the 'familiar' end of the spectrum which the authors attribute to the importance of conveying safety and trust. Campbell also claims the emergence of *the technological gaze* as a new way of seeing emerging in advertising of technology products (2007: 3), one that relies on specific methods: impossible subject-positioning, the codification of flesh, a visualization of scientific narratives and the aestheticisation of information. The more scientific images are incorporated into mass media such as advertisements, the more audiences will culturally develop ways to elicit meaning from them.

In conclusion, the radical nature of nanotechnology is stirring up debates regarding its relation to media. Some of the researchers' concerns are already discussed but it is important to note that those extend to other areas as well. Koshovets and Ganichev discuss the economic dimension of nanotechnology and express that the potential of nanotechnology '[...] may not be so great than anticipated' (2016: 546) which calls for a distinction between 'hype' and 'hope'. More researchers are worried about this 'hype' mentality. Selin comments on the temporal dimension of narratives that '[...] the term *nanotechnology* has been actively drawn toward the present to begin to deliver on the fantastic expectations' (2007: 196); and Umbrello studies the media coverage of nanotechnology in Italy and notes incongruence, one that he believes separates the 'normal nanotechnology' from 'speculative nanotechnology' (2019: 71). In a literature review, Boholm and Larsson attempt to define the root of the problem with nanotechnology communication and identify issues in every actor of the communication process: the public with its lack of critical knowledge, heterogeneity and emotional reliance; societal institutions; and lastly, nanotechnology itself because of its imperceptibility, epistemic uncertainty but also diversity and lack of dread risk (2019: 6-10).

It seems that nanotechnology as it currently stands is facing an identity crisis before it has even remotely matured. And this is without touching upon more sensitive issues related to it, like safety and health; these issues are beyond the scope of the present study.

Towards a typology of nanotechnology media

Two things were made evident from the literature review in the previous part. First, there is a great number of different media related to nanotechnology, each with a different purpose and target audience. Secondly, there is a strong expression of doubt about the feasibility of nanotechnology accomplishments, aptly described by the terms *real/speculative objects* and *real/speculative uses*. Motivated by these ideas, a typology will be proposed which covers all aforementioned cases and classifies the variety of texts depending on their use of images.

Let us consider again the types of media mentioned to this point. Scientific research papers are the first step towards the diffusion of scientific knowledge. Their audience is rather limited and consists of those who can understand the required terminology, dia-

grams and the rest of the scientific signification involved. The object of study is usually a real[5] object: a new material or process whose characteristics are examined. Educational material can be considered an extension of this kind of text, with terminology being toned down and simplified in favor of comprehensibility. But the objects presented remain real and not speculative, otherwise there would be no point in making them known. There is another kind of text aimed at a larger audience and that is advertisements. Ideally, they showcase real objects – unless it's false advertising. But unlike educational material, they have a totally different purpose: to sell, not to inform. Similar to the way anyone would expect to encounter differences in the use of language between a course book and a flyer, the use of images is also very different.

The final kind of texts discussed, art and fiction, also have an audience quite broader than those with a deep understanding of nanotechnology. However, the ideas presented, no matter how realistic they seem, are imaginary. This does not lower the quality or impact of these texts, they simply serve a different purpose.

This dual opposition between real/speculative and large/small audiences is reminiscent of the dual oppositions found in the semiotic square introduced by Greimas and Courtes (1982). Semiotic squares describe the fundamental meanings of texts. They have also been successfully employed to describe market segmentation (Oswald, 2015). A semiotic square is modeled by detecting a suitable pair of axes of opposing meanings. The four corners form relations of opposition, contradiction and implication (Fig. 1).

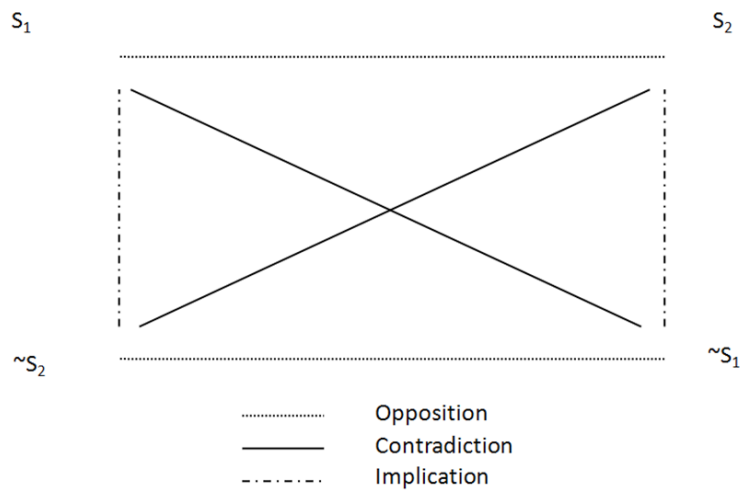

Figure 1: The structure of the semiotic square.

We could attempt a 'market segmentation' of nanotechnology media, in other words try to identify the basic structures of meaning behind them. The resulting axes would

show an opposition between *being-nanotechnology* and *seeming-nanotechnology*. This kind of semiotic square involving the concepts of being and seeming is called a veridictory square. Considering how many times fears about hype and speculation were expressed by researchers, this should be expected. *Being-nanotechnology* corresponds to the concept of real, actually devised objects while *not being-nanotechnology* refers to speculative objects. On the other hand, *seeming-nanotechnology* is related to the presence of cultural elements signifying the idea of nano- to the public, as well as the lack of advanced technical jargon that is potentially alienating and confusing. For something to seem nanotechnology, it matters little if there is no connection to real objects, as long as the impression of nanotechnology is cultivated. *Not seeming-nanotechnology* is the absence of any nanotechnology referents. The proposed square is shown in Fig. 2.

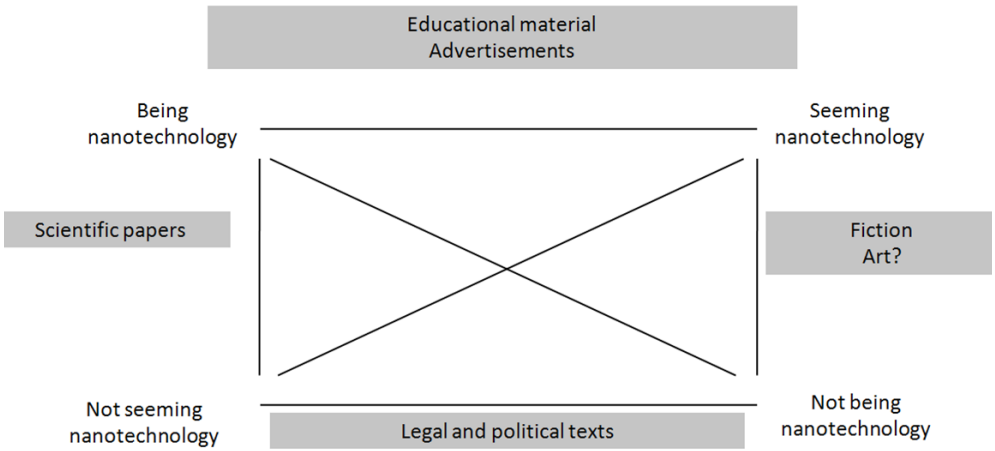

Figure 2: Semiotic square of nanotechnology in media.

It is reminded that the proposed square is based upon the use of images in the texts. It is therefore important to explain that the quality of seeming-nanotechnology does not refer to the availability of visual stimuli but whether those can be identified as *nano-* through culture. The nature of nanotechnology itself poses a challenge as its scale is beyond our senses. Being imperceptible, it is impossible to *seem nanotechnology*, therefore seeming and being nano- at the same time is actually an oxymoron. Also, with the field still under development, new, unfamiliar imagery is likely to be produced in the future. Being-nanotechnology often implies not seeming-nanotechnology and vice versa. As Loeve noticed, the ideas seem to be mutually exclusive.

The combination of neighboring corners in pairs leads to the final categorization. Texts combining being- and seeming-nanotechnology include advertisements and edu-

cational material. Scientific papers do not have the seeming-nanotechnology quality because they usually produce their own specific purpose images as mentioned earlier. Fiction may well use concepts of nanotechnology but lack a connection to a real nanospecimen.

To this point, the quality of seeming-nanotechnology has been linked to the ability to be identified by culture as nano- and as a result reach larger audiences. All but one of the combinations between the size of the audience and the objects represented have been discussed: is it possible for a text to address few but refer to a speculative nanotechnology object? Perhaps so. Texts of legal or political content explore possibilities instead of real applications of nanotechnology; at the same time they are hard to understand due to the legal terminology required to address them. With health and safety issues still open, it is expected that more legal documents detailing regulations for nanotechnology products will appear. The real topic of these texts is legal policies and any nanotechnology reference is speculative, not real.

The proposed model offers the possibility for even finer categorization. Artistic representations can be divided into digital visualizations accompanying verbal texts. This kind of art should be placed on the right side of the square (seeming but not being). If, however, art refers to artifacts created involving nanotechnology techniques, then it would fit near the top of the square (both being and seeming).

Let's take a finer look into advertisements as texts. Ideally, their aim is to present a real object by describing it in the best possible way, aggressively promoting its advantages over competition. In such cases, they should be placed on top, as shown in Fig. 2 (both being and seeming). But what if the nano-qualities were actually threats? With concerns raised about the safety of nanomaterials, it is possible that the product's origins would rather be hidden than communicated, bringing such an advertisement closer to the left side of the square (being but not seeming). Or, the product could be a fraud, bearing no relation to nanotechnoloy whatsoever but use the nano-narratives in its promotion to lure potential buyers. Then it would occupy the right side of the square (seeming but not being). It is evident that successful categorization of nanotechnology themed media requires good knowledge of context and purpose. The proposed semiotic square offers a solid step in that direction.

Nanotechnology in official EU discourse

The proposed text of study is a 44-page long document published by the European Commission in 2013 titled 'Nanotechnology: the invisible giant tackling Europe's future challenges' and it is divided in three parts. The first part serves as an introduction and a brief outline of the vision of the European Union for nanotechnology. The second part, which is the main body, describes in more detail the various funded projects, their scope and outcome. It lacks any financial information meaning it does not function as a financial report. It is simply meant to offer general information to the public about the current stand-

ing of research, which in the third part is predicted to bring exciting benefits, economic growth included.

The absence of numerical data entails that any information provided is mediated through verbal and visual elements. In order to classify the text according to the proposed semiotic square, these elements need to be analyzed. Due to their extensive presence in the document, verbal elements will be studied first and grouped in isotopies (semantic groups characterized by repetition of specific ideas). Images will be classified into four categories: abstract digital visualizations (artistic decorations with no connection to the accompanying text), digital visualizations of projects (depicting the expected deliverables of funded projects), scientific images (found within published papers) and real life images (macro images objects).

Results

The verbal text describes nanotechnology as a field involving the activity and labor of actual people. Exact quotes of perceived authorities on the matter are referenced: Richard Feynman (Nobel laureate and for many the 'founder' of nanotechnology), Gordon Moore (co-founder of Intel corporation), Aidan Quinn (Head of nanotechnology group, Tyndall National Institute, Ireland) and Máire Geoghegan-Quinn (European Research, Innovation and Science Commissioner). It is not a mere appeal to authority though, since a direct implication 'of at least 55000 researchers' in Europe is also mentioned. The narrative employed is suggesting that nanotechnology is not developed in a lab beyond reach by unknown institutions, it is an activity done by and for humanity (isotopy of humanity). Definitions of space and time are frequently used. Nanotechnology is described to 'make everything better', it features 'all-pervasive technologies', with the authors wondering if there is 'any aspect of modern existence that nanotechnology will not touch'. These claims imply that nanotechnology is everywhere (isotopy of omnipresence). But it is also imminent: the use of tenses is limited to present and future and a set of expressions ('in the future', 'within the next 10-15 years', 'within a decade') describes actions to take place in the near future (isotopy of imminence).

An elaborate list of nanotechnology applications is provided within the document: 'self-cleaning clothing', artificial issues', 'water filters', 'RFID food packaging', electric/hydrogen cars', 'quantum computers', 'flexible screens'. Consumers would have every reason to feel optimistic about the future because nanotechnology is described to be very powerful (isotopy of power). But since powerful can sometimes mean dangerous, another approach is used in parallel: the new scientific domain is presented to bring 'innovation', 'opportunities', 'efficient use of resources', 'sustainable growth', even has a 'recipe' for self-assembly (p. 23). The latter is the manufacturing of materials with minimal external control, a process considered a vastly superior form of engineering. Although it is never stated that self-assembly was achieved, the use of the word 'recipe' to describe

a project is an oversimplification. These everyday terms create the reassuring narrative that nanotechnology is familiar (isotopy of familiarity).

Finally, in case someone is worried about potential dangers of the increased control over matter, a series of phrases pointing out that it is safe and ethical is provided (isotopy of safety). Moreover, the aim of the author is clearly stated in this case 'But as with any novel technology, the public will want to be reassured and informed of the safety of new products'. It also added that there is '"[...] consideration of health, safety and environmental impacts' and that the EU has '"[...] since 2004, pledged to take an "integrated, safe and responsible approach to nanotechnology'.

Moving on to the study of visual elements, the document has fifteen images in total. The majority (ten out of fifteen) are abstract visualizations created by digital means, two are digital visualizations of funded projects, one is a scientific image taken by means of microscopy and two are real life images. These are from a lotus leaf (the 'lotus effect' refers to the hydrophobicity of water droplets on lotus leaves and is a common example used for the popularization of nanotechnology). The second one is the front of the Slovenian National Building and Civil Engineering Institute ZAG, where the solar panels of a funded project were installed. Examples of each category are shown in Fig. 3 and the results are summarized in Table 1.

It is noteworthy that instead of providing some clear indication of the standing of current research, these images create a sense of vagueness. The abstract visualizations do not correspond to any specific project and do not depict anything in particular. They are,

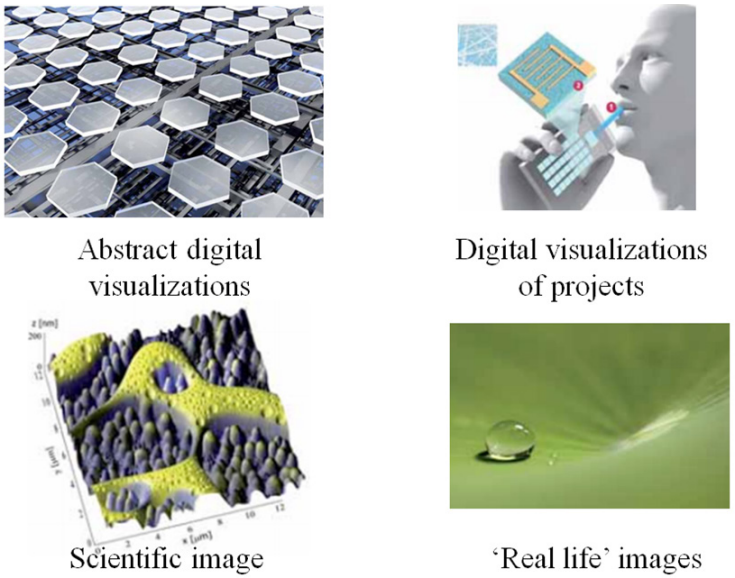

Figure 3: Examples of different types of images.

Table 1: Percentages of different types of images

Type of image	Number of images	Percentage
Abstract digital visualizations	10	66.7%
Digital visualization of actual projects	2	13.3%
Real life images	2	13.3%
Scientific images	1	6.7%
Total	15	100%

however, accompanied by the name of the artist and the website of stock photos that were taken. The visualizations of actual projects are few and there is no image of actual product to compensate. 'Real life' images simply provide a setting and also lack a link to a specific project. Finally, there is only one scientific image (shown in Fig. 3) which is a microscopy image, therefore easy enough for the reader to perceive as a magnification. The author's aim to create a text addressing a large audience is clearly reflected in the use of images. Based on the proposed typology, the document would be placed on the right side of the proposed semiotic square, along fiction: it needs to appear as a nanotechnology text but has few real connections to it.

This is further supported by the verbal elements of the text. No specialized knowledge is required and the effort to present an idealized version of the future is evident. In fact, the isotopies identified could be narrowed down to only two: power (incorporating the isotopies of power, omnipresence and imminence) and safety (incorporating the isotopies of humanity, familiarity and safety). This is the underlying predominant message: nanotechnology is powerful enough to solve many problems and create a better future but also safe enough to lull our worries and encourage our trust.

Conclusions

The gap between scientific knowledge and mass adoption of new ideas has always been a challenging one to bridge. As new knowledge demands more complex processes to be reached, so will difficulty in communicating it. By focusing on nanotechnology, a discipline approaching almost half a century, it was demonstrated that a critical reading of texts is important for understanding the deeper cultural issues at play. With researchers already expressing concern about the feasibility of projects and the failure to deliver upon promises, it is time to start examining the role of texts accompanying science more carefully as well as the way they develop in parallel to the research itself.

In order to do so, most common issues raised in the literature were used as a starting point to reach a veridictory semiotic square based on the opposition between being- and seeming-nanotechnology. Based on that, nanotechnology texts combine these qualities differently and can be categorized into advertisements, educational material, scientific

papers, legal documents and art. These are but the most obvious types concluded, with further segmentation possible should new types of media are met. This approach is essential if we are to fully assess how they function and prevent false concepts of applied science from entering the public sphere.

Marketing media are usually on the receiving end of strong critique but it is important to understand that much more than product success is at stake. A critical approach should include a complete change of our view on RnD, distribution channels, marketing, education and the way all these interact in order to meet actual social necessities and not fabricated ones. If the necessary effort is not placed into carefully examining context, any classification remains redundant. A published scientific paper could have more in common with an advertisement if its sole purpose is to secure financial funding.

The proposed semiotic square was applied to only one document due to constraints but its effectiveness is demonstrated by the ability to deal with a type of text previously not addressed in the literature. The EU document under study revealed a plethora of unsupported claims and the downplaying of attainability issues, characteristics that place it closer to fiction than anything else.

However, the aim of this study is not to make an impression. If nanotechnology –or any other modern technology for that matter– is to go beyond marketing agendas, then it should make careful use of images and narratives to avoid being labeled as another 'hype'.

Endnotes

1. The term *nanoethics* is often used in literature to describes topics regarding the safe and responsible use of nanotechnology.
2. The Scanning Tunneling Microscope or STM is a fundamental scientific instrument in nanotechnology and is often considered a symbol for nanotechnology as a whole.
3. Most researchers consider that nanotechnology was established in 1959 when Nobel Laureate Richard Feynman gave his lecture *There's plenty of room at the bottom* describing atom scale manipulation of matter, although some researchers question this and consider it '[...] a cheap way of garnering scientific authority' (Milburn 2002: 277). The STM was invented in 1981, so Drexler's book was published when nanotechnology was in its early development.
4. At least those advertised as such. Most modern electronic devices, like smartphones, have at least some parts of them measuring nanometers but this fact is often omitted in advertisements, possibly due to avoid stirring worries about safety.
5. The ontological question of the nature of a 'real' nanotechnology object is beyond the scope of the current study. The term here simply refers to the novelty that comes with each new research object.

References

Allamel-Raffin, Catherine. 2011. 'The Meaning of a Scientific Image: Case Study in Nanoscience. A Semiotic Approach'. *Nanoethics*, 5: 165–173.

Birkeland, Tore and Roger Strand. 2009. 'How to Understand Nano Images'. *Techné*, 13: 182–189.

Boholm, Åsa and Simon Larsson. 2019. 'What is the problem? A literature review on challenges facing the communication of nanotechnology to the public'. *Journal of Nanoparticle Research*, 21(86). Available at: https://bit.ly/3e5Ltmq (accessed 5th October 2022).

Bontems, Vincent Karim. 2011. 'How to Accommodate to the Invisible? The "halo" of "nano"'. *Nanoethics*, 5: 175–183.

Campbell, Norah. 2007. 'The technological gaze in advertising'. *Irish Marketing Review*, 19: 3–18.

Campbell, Norah, Cormac Deane, and Padraig Murphy. 2017. 'The sounds of nanotechnology'. *Nature Nanotechnology*, 12: 606–610.

Campbell, Norah, Cormac Deane, and Padraig Murphy. 2015. 'Advertising Nanotechnology: Imagining the Invisible'. *Science, Technology, & Human Values*, 40: 965–997.

Chen, Chaomei and Diana Hicks. 2004. 'Tracing knowledge diffusion'. *Scientometrics*, 59: 199–2004.

Dondero, Maria Giulia and Jacques Fontanille. 2014. *The Semiotic Challenge of Scientific Images. A Test Case for Visual Meaning*, Julie Tabler, trans. Ottawa: Legas Publishing.

Drexler, Kim Eric. 1986. *Engines of Creation*. Garden City. N.Y: Anchor Press/Doubleday.

European Commission. 2013. *Nanotechnology: the invisible giant tackling Europe's future challenges*. Luxembourg: Publications Office of the European Union.

Greimas, Algirdas Julien and Joseph Courtés. 1982. *Semiotics and language: an analytical dictionary.* Bloomington: Indiana University Press.

Hvidtfelt Nielsen, Kristian. 2008. 'Nanotech, Blur and Tragedy in Recent Artworks by Gerhard Richter'. *Leonardo*, 41: 484–492.

Kaminska, Aleksandra. 2015. 'Designing Nano-Media Across Disciplines: Circular Genealogies and Collaborative Methodologies at the Optical Frontier', in *ISEA 2015 Proceedings of the 21st International Symposium on Electronic Arts*. Vancouver: ISEA International, 670–677.

Koshovets, Olga and Nikolay Ganichev. 2016. 'Nanotechnology Contribution to Innovation-Driven Growth: Hype or Hope?'. *Economy & Business*, 10: 546–561.

Kress, Gunther, and Theo Van Leeuwen. 2006. *Reading images: The grammar of visual design*. London: Routledge.

Oswald, Laura. 2015. *Creating Value - The Theory and Practice of Marketing Semiotics Research*. Oxford: Oxford University Press.

Loeve, Sacha. 2018. 'Design and Aesthetics in Nanotechnology', in *French Philosophy of Technology. Classical Readings and Contemporary Approaches*, Sacha Loeve, Xavier Guchet and Bernadette Bensaude-Vincent, eds. Cham: Springer, 361–384.

López, José. 2004. 'Bridging the Gaps: Science Fiction in Nanotechnology'. *Hyle*, 10: 129–152.

Milburn, Colin. 2002. 'Nanotechnology in the Age of Posthuman Engineering: Science Fiction as Science'. *Configurations*, 10: 261–295.

Mößner, Nicola. 2018. *Visual Representations in Science, Concept and Epistemology*. London and New York: Routledge.

Ottino, Julio M. 2003. 'Is a picture worth 1,000 words?'. *Nature*, 421: 474–476.

Robinson, Chris. 2004. 'Images in NanoScience/Technology', in *Discovering the Nanoscale*, Davis Baird, Alfred Nordmann and Joachim Schummer, eds. Amsterdam: IOS Press.

Selin, Cynthia. 2007. 'Expectations and the Emergence of Nanotechnology'. *Science, Technology & Human Values*, 32: 196–220.

Slaattelid, Rasmus Tore, and Fern Wickson. 2011. 'Imag(in)ing the Nano-scale: Introduction'. *Nanoethics*, 5: 159–163.

Umbrello, Steven. 2009. 'Explorative Nanophilosophy as Tecnoscienza: An Italian Perspective on the Role of Speculation in Nanoindustry'. *TECNOSCIENZA: Italian Journal of Science and Technology Studies*, 10: 71–88.

Xie, Charles, and Hee-Sun Lee. 2012. 'A Visual Approach to Nanotechnology Education'. *International Journal of Engineering Education*, 28: 1006–1018.