Petra Černe Oven

Visual Communication Design and its Role in the Easier Understanding and Effective Retention of Ideas, Information, and Concepts in the Field of Science

In today's world, it is easy to be pessimistic. The well-known expression "wicked problem" is not merely a buzzword. It has become a common expression allowing for the possibility of turning a blind eye to challenges for which we are responsible but that we don't know how to face.

The speed of technological development in our society has never been as fast as it is today, and new technologies and media influence us on every level of our lives. Due to the vast amounts of freely available data and its aggressive dissemination on diverse platforms, it is crucial that information is presented in a clear and understandable way. This applies to all disciplines, but is especially important for areas of scientific research and education where the successful presentation of discoveries and the clear and understandable explanation of concepts is paramount. In the last three decades, the democratisation of media and tools through digitalisation has led to an increase in the use of images, and it has become increasingly important that visual means of knowledge representation in science are deeply understood, methodologically developed, and professionally applied.

This paper introduces the importance of visualisation in science, building on key advances that that have already been made in the field of visual communication design. The target readers for this paper are not designers, but scientists. Designers and scientists share the belief that it is high time that we begin to use all available media to convey important messages. Imran Khan, Chief Executive of the British Science Association, argues that science is "too important to be left to scientists alone" (Khan, 2015). He believes that science and its uses can be greatly enhanced and shaped by society and that "the purpose, direction, ethics, and sustainability of science and innovation have to be defined by society as a whole" (British Science Association, 2015). But if we want the public to take part in the discussion, the topics must be understood by both scientists and the public. I would not be the first person to note the obvious point: excellent science – the result of hours and hours of research in the archives or working at the bench in the lab – is not the end of the story. Scientists also need to communicate their findings. In order to generate public engagement on difficult topics, we must be capable of communicating science to everyone. A key question for scientists is therefore: how do we compete with all the other distractions and grab the public's attention? Because scientists have such an important role in our society, I will argue that now is the time to use all available tools to get their message across. And visual communication designers are here to help.

In this article, I do not address the situation from the perspective of visual art theory as it has been discussed in other works (Arnheim, Butina, Muhovič), or of individual disciplines within the broad field of visualisation (such as the visualisation of data as Tufte has done). I also do not focus on the field of visualisation from the perspective of behavioural change in the cognitive domain (visualisation for imagination and creativity). Instead, I will focus on the field of visual communication design where objective information is communicated through visual messages. In other words, in this paper, I will not explore images in general (either in media, film, popular culture, art, or society at large), but rather focus on cases where science can make use of very specific visual material to support arguments, and what role this approach could play. I am referring to visual material that is produced through the research process, illustrates research findings, builds arguments based on data, or presents information about scientific facts, processes, and results so that they are more understandable and therefore facilitate particular transfers of knowledge.

Historia magistra vitae est

Throughout the history of science, text and textual messages have been the dominant norm of communication. People lectured, gave speeches, and wrote articles – all with words. Words prevailed, but we must not ignore the many exceptions to them. Visual language developed in parallel with the development of science, and many prominent scientists used visualisation to think, build their arguments, present them more coherently, and disseminate the outcomes of their research.

Leonardo da Vinci is probably one of the most renowned users of visual language. As he sketched, he defined patterns that helped him reason further. More than 360 years ago, it was already established that the combination of text and images in educational materials was more effective than text alone. We see an example of this approach in Johann

Amos Comenius's book for children, *Orbis Sensualium Pictus*, published in Nuremberg in 1658. Schematic family trees, showing the relationships between people over long periods of history, also date from this period. The seventeenth century also saw the development of empirical data tables in mathematics, and similar concepts in cartography in geography.

The eighteenth century, when the conditions of society made it possible to reflect on the different components of the interpretation of history and the contexts of historical events, became a key period for the development of visual representations of themes. By this time, two contrasting modes of visualisation had already emerged: the first used highly authored visual structures that instructed the viewer what to think, while the second used patterns in the data that appeared more automatically and could be interpreted by the viewer (Boyd Davis, 2017).

This fertile time of visualisation is relevant in the context of this paper, but due to space limitations we cannot discuss all the authors in depth. The British scientist and liberal political theorist Joseph Priestley (1733–1804), who created the first charts in which individual lines were used to visualise a person's lifespan and the whole could be used to compare the lifespans of several people, was certainly one of the most advanced (Priestley, 1765). In 1769, Priestley published *A New Chart of History*, which illustrated his belief that a diagrammatic representation of the entire history of the world could easily present the rise, progress, extent, duration, and current condition of all the major empires that had ever existed. It dealt with the impact and dominance of individual historical empires as well as the ideas, events, and people involved. The density of the entries in the display shows both the immense vitality of the era, and the causes and consequences of events.

During this period, the English political economist William Playfair (1759–1823), who made history as the inventor of the visualisation of statistical data in graph form, was also active. He invented most of the formats that we still use today. Later, visualisations would also be used in the thinking and presentations processes of other top scientists, such as Charles Darwin, who used conceptual sketches to develop his theory of evolution in the nineteenth century (Atzmon, 2015).

Both the dissemination of information and the accessibility of media have seen ongoing enhancements with the development of printing processes. At the same time, the ability to generate and use pictorial material has also improved with the development of new technologies. The Industrial Revolution brought a major leap forward in development, creating both new communication needs (advertising, timetables, and maps) and stimulating further innovations and growth in the printing industry. Later, technology facilitated the faster typesetting of verbal messages with machines such as the Linotype and Monotype as well as a much wider range of possibilities for the reproduction of pictorial material with lithography.

These inventions also led to important breakthroughs in the communication of scientific content. An example of this can be seen in one of the books published by Oliver Byrne (1810–1880), a civil engineer and prolific author of works on mathematics, geometry, and engineering. He decided to have woodcuts made to illustrate the geometric elements presented in the book (Byrne, 1847), using colour as the primary medium of information. He argued that, with this clear and simple method, the reader would be able to learn geometry in one-third the time they needed with ordinary books, and that the knowledge would remain with the reader longer because visual images of the material are better remembered.

One of the most historically significant documents in the field of visualisation was the map or diagram of Napoleon's march on Moscow, designed in 1869 by the French engineer Charles Joseph Minard (1781–1870), illustrating the French Army's invasion of Russia from 1812 to 1813. The document is a diagram or spatial map that illustrated in two dimensions a range of statistical variables in space, such as the location of the army and the direction in which it was moving, the size of the army, the separation and amalgamation of units, the reduction of the army, the temperatures at which they were fighting, and so on. A single glance at Minard's diagram gives us almost all the information we would otherwise extract from complex written descriptions. It is interesting to note that, in visual terms, it uses spatial distribution for the most important dimensions of the data and other visual variables – such as colour, line thickness, etc. – for other less important dimensions.

Scientists in the past have also used visual means as tools in the scientific process. Other authors have already researched this interdisciplinary field. For example, Alan J. Rocke (2010) discusses the work of the nineteenth-century German chemist August Kekulé, who claimed to have mentally visualised the ring structure of benzene. Rocke makes the argument that human minds work far more visually and less linguistically than we realise. He makes his point by naming a number of early chemists who used their imagination to visualise the constitution of the micro-world and to provide pictures of it before the technology was available to disseminate such pictures, that is, before we were able "to see" with the help of tools or machines.

As we move into the twentieth century, Albert Einstein must be mentioned because he relied greatly on mental visualisation to construct his theories. (For that matter, Isaac Newton also used drawings in explanations of his experiments.) The first three decades of the twentieth century saw the increased use of visual materials in a range of scientific fields. We can find an example in the social sciences of the visual language that would lay the foundation for thinking about the democratisation of information. The Austrian philosopher, sociologist, and political economist Otto Neurath (1882–1945), one of the leading intellectuals of the Vienna Circle, and his colleagues (Marie Neurath and Gerd Arntz) developed the ISOTYPE system, which used graphic symbols to represent complex quantitative information in a simple and comprehensible way. They used the system to educate people about the infectiousness of diseases and causes of mortality as well as social and political issues. Their work was extremely important for the education of the whole population, regardless of literacy level. Isotype visualisations encouraged people to actively change their behaviour and were applied in many countries, also outside of Europe, as verbal language (with diverse writing systems) was not the primary carrier of the information.

A well-known example from more recent history, which included photography and sketching, can be found in the identification of DNA's double helix structure by James Watson and Francis Crick. In 1952, Rosalind Franklin and Raymond Gosling took a photograph (titled Photo 51) at the Biophysics Department of King's College London that showed the x-ray diffraction pattern of DNA. Franklin and Gosling obtained these images of DNA using x-ray crystallography. The images were then shown (via Maurice Wilkins) to James Watson, and were crucial in helping Watson and Crick to create their famous double-helix model of DNA. This was not an artistic photograph (Walsh, 2012), but the result of a process, and it gained iconic status because it inspired Crick to make a pencil sketch of the DNA model. Both the photos and the pictures were essential parts of the research process that led directly to the most important scientific discovery of the twentieth century. Several years later, Francis Crick, James Watson, and Maurice Wilkins shared the 1962 Nobel Prize for the discovery of the structure of DNA and the double helix model.

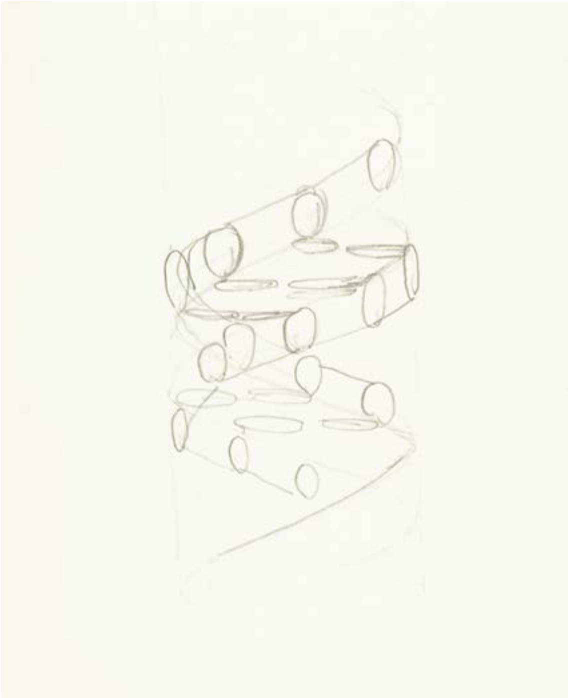

Figure 1: Pencil sketch of the DNA double helix by Francis Crick, showing a right-handed helix and the nucleotides of the two anti-parallel strands. Wellcome Collection. Attribution 4.0 International (CC BY 4.0), retrieved from https://wellcomecollection.org/works/kmebmktz

Continuing in the field of natural sciences, we can discuss an example from the other side: visualising science by a professional designer and not a scientist. The design was created by Will Burtin (1908–1972), the German pioneer of information design, who emigrated to the United States in the 1930s. He was positively inclined toward all scientific fields, and although a creative designer, he always put scientific research at the centre of his attention in his projects. As an art director for the Upjohn Company, Burtin was given the assignment of instructing the general public about the structure of a cell, and the resulting design, which emerged in the context of the developing field of cell biology, serves as an exemplary visualisation that is not limited to two-dimensional space.

Burtin contacted the leading scientists of the time and, in collaboration with them, gathered data and information to use as the basis for a project. With this knowledge, he designed a three-dimensional special structure – a visualisation model – that scientists themselves could not envision, and used the model as a tool for educating the public. The model was an installation made of a mesh structure with plastic pipes on the perimeter (membrane), plastic pieces inside (mitochondria), and an energy-glow sphere in the middle (denoting the cell core). The sculpture, powered by electricity, gave the impression that the cell was actually alive. Burtin's model, through which visitors could freely move, was not just an augmentation of reality but rather a diagrammatic and moving model to illustrate processes and functions in the cell that the world was just beginning to understand.

The project was based on the active collaboration of a designer with professionals from various other disciplines, this type of cooperation being the essential feature of such projects. After this success, Burtin continued to work and prepared several more exhibitions, including a spectacular model of the human brain (1960), metabolism and blood circulation (1963) for Upjohn; and atomic energy (1961) for the Union Carbide Company. His projects were built on scientific data but visualised through symbolism, metaphors, and direct diagrams that were easy to perceive and understand. Even today, projects such as Burtin's are considered exceptional examples of successful communication, not only because of the presentation of the topic as such but also because of their impact on society as a whole. Many fields of science are compelling because their ethical, moral, or economic values are significant for civil society and have the potential to influence legislation, court decisions, developments in medicines, and investment decisions. Because of this, science is obliged to communicate scientific results both to the private and public sectors in an understandable way.

Visual language and visualisation in human cognition

Despite the emphasis of science on verbal communication in the past, we have actually become a much more visual society in recent times. This has also been acknowledged by many contemporary thinkers in recent history, among them W. J. T. Mitchell who investigated this theme in his 1994 book *Picture Theory*. In the book, Mitchell explores how modern thought has reoriented itself around visual paradigms, and argues that this transformation is occurring in both the human sciences and the sphere of public culture. He calls this shift the pictorial turn. Complex theories about pictures, picture theory, and the visible have been developed, and there are many thinkers who have tried to defend "speech" against "the visual". Mitchell believes this is "a sure sign that pictorial turn is taking place" (Mitchell, 1994, p. 13). Mitchell further argues that we should "reflect on the commonplace notion that we live in a culture of images, a society of the spectacle, a world of semblances and simulacra. We are surrounded by pictures; we have an abundance of theories about them […]" (Mitchell, 1994, pp. 5–6).

Another contemporary author, Robert E. Horn, went so far as to define the integration of words, images, and shapes into a single unit of communication as an entirely new language: *visual language*. He pointed to an increasingly complex world with a proliferation of problems and the ambition to solve them, and to the development of media and technology in the 1990s, as the driving forces behind the development of visual language (Horn, 1998, p. 11).

We can see evidence of the increasing use of visual material around us every day. This fact can be powerfully illustrated by the interactive visual display of the front page of the. In this example we can follow the increasing inclusion of visual material from the mid-nineteenth century onwards: from text-only to black-and-white photographs to full colour photographs. As well as the number, the size of pictures has grown, too.

In the last two decades, the importance of the visual has been acknowledged in many fields and begun to be optimistically explored in science. Scientists are steadily increasing the amount of visually communicated content. As early as 2015 when I contributed to an information design conference in London, I recall the *Guardian* advertising "science communication masterclasses". Since 2016, over one hundred medical journals and organisations, have adopted visual abstract formats (Millar & Lim, 2022, p. 71). Scientists are aware that the use of visual abstracts is increasing the visibility of research articles (for example on social media), resulting in a greater number of views and engagements (Oska et al., 2020). In 2021, we held the first national symposia on visual literacy at the Cankarjev dom Congress Centre in Ljubljana, Slovenia, which explored issues connected to the role of the visual in education and emphasised the many benefits that visual language has for successful communication.

The growing utilisation of visual images in science and society as a whole can be attributed to fundamental aspects of human cognition that are now being better understood and harnessed with greater precision. While designers aim to explore, understand, stimulate, and incorporate all the senses in product development and communication, neuroscience has confirmed the paramount importance of visualisation in human cognition.

Half of the nerve fibres in our brain are connected to our vision. When our eyes are open, vision accounts for two-thirds of the electrical activity in the brain. We recognise images very quickly: it takes the brain only one hundred and fifty milliseconds to recognise an image, and one hundred milliseconds longer to attach meaning to it (Raworth, 2018, p. 13). Several studies show that the human brain is able to process an entire image that it sees in only thirteen milliseconds. In one study, scientists showed people a series of images that were visible for between thirteen and eighty milliseconds. Viewers successfully identified motifs such as "picnic" or "smiling couple" despite the extremely short times they were visible (Potter et al., 2014).

Of course, it is not just about perception. Zvezdan Pirtošek, cognitive neuroscientist, explains that in the early stages of visual processing, the eye and brain decompose the visual image into basic elements (points of light, lines, edges, colours, movement), and then in the later stages, the visual image is reconstructed into complex images in which objective and subjective reality are intertwined according to a hypothesis we set for ourselves (Pirtošek, 2016).

Information presented in the form of an image rather than words or numbers is also easier for the brain to process. The right hemisphere recognises shapes and colours. The left hemisphere of the brain processes information analytically and sequentially and is more active when people are reading texts or looking at spreadsheets. Looking at a numerical table requires significant mental effort, but visually presented information can be understood in seconds because the brain recognises patterns, relationships, and relationships between visual values. This means that visual imagery also reduces the energy needed to process information, thereby maximising the energy left for thinking and effective action (Rock, 2009).

Since the Enlightenment, sight has been recognised as the most objective sense and is therefore linked to the mind, reason, rationality, and logic. Sight is also our main sense, and our world as we perceive it is visual. "Visual acuity measures more than just vision; vision is the process of extracting meaning from what is seen. It is a complex, learned, and developed set of functions involving many skills. Research estimates that eighty to eighty-five percent of our perception, learning, cognition, and activity is done through vision" (Politzer, 2008, n. p.). As we are dealing with a very specific area in this article – the purposeful transmission of information and understanding – we therefore reemphasise our main premise: that visual perception is extremely effective in the field of science.

Professional or lay visualisations?

British designer Norman Potter (1923–1995) wrote the following in his book *What is a Designer?*: "Every human being is a designer. Many also earn their living by design – in every field that warrants pause and careful consideration, between the conceiving of an action and the fashioning of the means to carry it out and an estimation of its effects" (Potter, 1980, p. 13). I will now briefly touch on a fascinating area of visualisation that deals with not the professional execution of visual communication, but vernacular or layman's visuals. From experience, we know that drawing comes naturally to children, but as we grow up we stop drawing. This turns out to be a great loss because sketching and drawing to illustrate thoughts or processes has many positive characteristics. Drawing helps us establish a common focus and concentration when working in a group. It promotes interactivity and involvement, efficiency, and better collaboration, and enables better listening, understanding, and remembering.

Drawn concepts are generalised and abstracted, allowing us to think about them without limitations. They can be modified, improved, and developed through group work and collaboration. Sketching also helps us to articulate concepts or beliefs, invites collaborators to change their perspectives, and has an organic authorial voice. The visual language of drawing contains a different organic energy than computer generated graphics. It helps to stimulate out-of-the-box thinking because concepts are not predefined. In addition, a handmade drawing has another important attribute: it is memorable.

Let's look at what one student of biology in Slovenia, Nina P., did during the COVID-19 pandemic (Stegnar, 2021). She took a piece of paper and translated the information about mRNA vaccines and viruses into a comic in a polite but humorous way. She wanted to present the complex topic in a simple manner, because she knew that reading academic articles can be difficult, if not impossible, for the lay public. She was eager to negate many of the theories that were floating around at the time (microchipping, DNA modification) and were entirely wrong. In this sense, the naïve comic was a successful way of fighting fake news and she was able to reach the public.

The example confirms that an amphibian nature is an asset. Many scientists are good with visuals; nevertheless, collaboration is usually the better option. Using an interdisciplinary approach to solving communication problems, each profession can contribute their expert knowledge and insights. Artists and designers know the theory behind their solutions, and they can build on the comprehensive field of visual theory that already exists. Indeed, it has been shown that there are beneficial effects to having artists and designers on scientific research teams (Springs & Baruch, 2021).

Diverse design fields and their characteristics

We will now look at the design profession. As a discipline at the crossroads of science, art, and technology, design has developed many specific fields through history (for example, product design, graphic design, experience design, information design, interactive design, service design, design thinking, speculative design, etc). Norman Potter classified design into three neat and simple groups: things, places, and messages. The last one, messages, deals with visual communication design, which is just a tiny fraction of the design we encounter each day of our lives. Visual communication design is the art of conveying messages by visual means, and it is ubiquitous. The public often associates design exclusively with corporate capitalism (for example, branding and advertising), but these stereotypical perceptions need to be overcome. There is amazing potential in the collaboration between scientists and designers because visual communication design interprets and explains texts, data, concepts, and processes through clear language, effective illustration, typography, photography, graphics, and other visual communication tools.

This paper is specifically focused on design that is "concerned with ideas and problem solving on technical, functional, aesthetic, economic and socio-political levels" because "through intelligent use of tools and resources, a better outcome can be achieved, and for less money" (Odling-Smee & Kent, 2013, n. p.).

The field of visual communications itself is very broad and draws on a combination of many different disciplines: typography, graphic design, illustration, photography, interactive design. Each of these disciplines has enormous potential for communication. If we look at typography, for example, we notice that texts can articulate a verbal message in many ways. When designers are experimenting with the configuration of certain texts, they have many available options (pure linear, linear interrupted, list, linear branching, matrix, non-linear directed viewing, non-linear, combinations). At the same time, designers must decide on the method of symbolisation, whether it should be verbal, numerical, pictorial, schematic, etc. Not only articulation and layout (which is connected to the space where the articulation is taking place), but also the style of the chosen typeface is crucial: letter-shapes communicate about the authority, power, degree of formality or informality of the message. They make the typeface more or less legible, thus affecting the readability of the conveyed message.

After the text, the next area of visual communication design is illustration, a field that is so broad that it alone could be the subject of a whole series of lectures and papers. We broadly classify illustration into two distinct fields: fiction and non-fiction. Non-fiction refers to faithful representation, and is further divided into popular-scientific and scientific. The latter is particularly important in the context of this paper. We divide it into the natural (botanical, zoological, habitat, geological, paleontological, astronomical, cartographic, anthropological), the medical (anatomy, pathology, surgery), and the social (ethnological, archaeological, historical). Each area has slightly different approaches, as each specific scientific field has an influence on the norms, criteria, and methods of visualisation.

However, this is not the sole classification for illustration. We can also classify illustrations according to their form and objectives – narrative, naturalistic, conceptual, informational, and technical – and specific uses depend on the impact we want to achieve. For example, a conceptual scientific illustration is situational, emphasising the broader topic or story it is intended to summarise, an approach that is often used in graphic abstracts for academic papers.

Although the specifics of form and medium are extremely important, amateurs all too often forget them in their search for solutions. To illustrate with an example, a realistic photo of a heart for a medical anatomy book could be a factual element on the page, but when students need to learn something from it, it would be better to choose a realistic scientific illustration. To provide more information, it is generally better to use illustrations with diagrams, appropriate typography, and clear language methods (supported by colour and other rationally defined elements) than photographs.

Apart from illustrations, visual communication design often uses photography. Each discipline has its own specific strengths: photography can show us a diversity of information, while illustration tends to emphasise focused information. Photography shows the specificity of the object, while illustration depicts universality. Realistic photography has unadapted perspective and colour, while illustration can choose perspective and colour. Photography portrays visual variety, while illustration portrays unification.

Communication needs also differ. When we are dealing with politically engaged communication, we will probably use completely different tools: shock, realism, exact words, all of which have a powerful impact on public opinion. There are many of examples of such persuasive communication around us.

As we saw in the historical examples discussed above, sometimes visual communication can help us visualise things that cannot be seen by the naked eye. We can also visualise unrealistic scenarios that make people aware of important issues related to society or the environment, and therefore invite them to think about the topic. As Christopher Hatton pointed out: "as a society we must learn both to look honestly at what lies ahead and work to cultivate the kind of social solidarity and cohesion necessary to weather the coming storms" (Hatton, 2022, n. p.). And because "difficult and frightening truths about the decades ahead can be tackled through art, literature and film", it is increasingly important that scientists recognise these media as potential tools.

A growing number of design and art projects bring together science and art with the common interest of informing the public about important discoveries in scientific fields. An example of such project is *Sense of Healing*, neurotherapeutic AI data sculpture by Refik Anadol, which poetically presents research that lies at the intersection of neuroscience and media arts to visualise different aspects of the human brain.

Exact visualisation may be the only way to perceive and understand an important message. This can be seen in the poster of the British slave ship Brookes that appeared in 1788 (Gilbert, 2020). Despite some flaws, the poster raised awareness through shock value, and helped to sway public opinion regarding the abolishment of the slave trade.

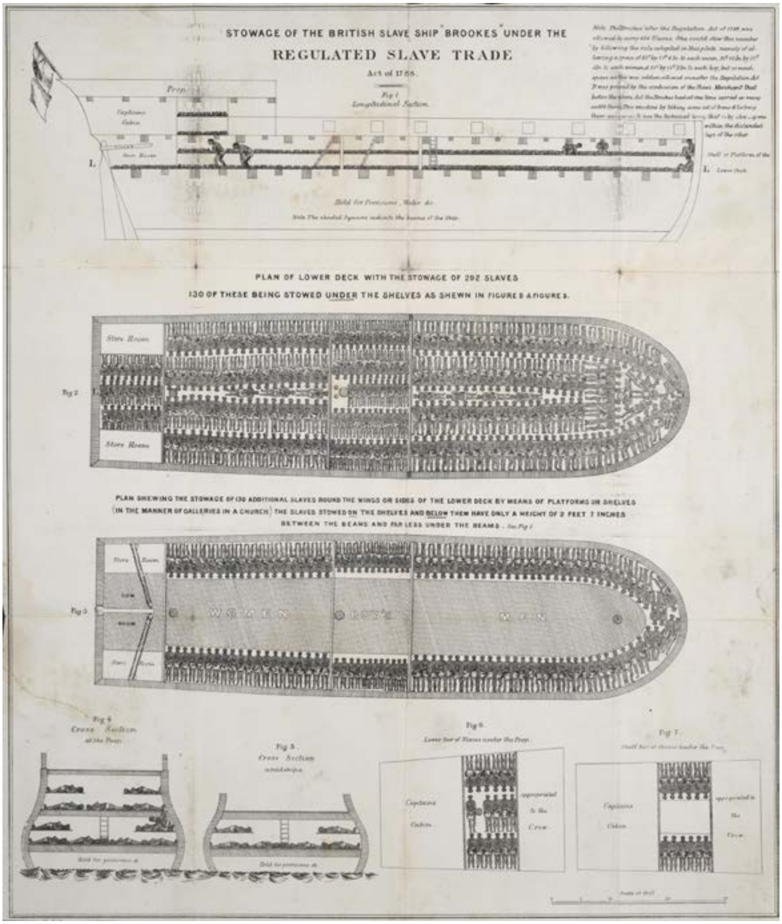

Figure 2: Stowage of the British slave ship Brookes under the regulated Slave Trade Act of 1788, retrieved from https://commons.wikimedia.org/wiki/Library_of_Congress

Building elements of visual language

As mentioned earlier, there are many diverse elements of visual language. In visual communication design, we usually communicate with verbal elements (individual words, phrases, sentences, bodies of text), shapes/graphical elements (points, lines, abstract shapes, negative space), and images that carry semantic meaning (illustration, photography). All of these elements are designed, featuring attributes that are controlled by variables: thickness, texture, colour (hue, saturation, value), orientation, size, position within 2D or 3D space, motion, etc. Combined into a whole, these elements constitute a visualisation. The variables are supremely important. In addition to their inherent value, they also influence each other. Accordingly, they must be chosen deliberately, both in terms of their functional transformation and their visual image.

With those basic building blocks of visual language, designers build visualisations. They can roughly be categorised into static (largely, but not exclusively, two-dimensional, for example, icons, pictograms, diagrams, charts, tables, maps, spreadsheets, and infographics), and motion or interactive (allowing us to better utilise three-dimensional space; examples include interactive graphics and data visualisations).

Depending on the intent and/or the research question, various information can be displayed through visualisation: when something started, the position of something in time, how long something took; the quantity of something, what proportion did each quantity represent in relation to the whole; the order, the sequence of things; the categorisation of items according to specific parameters or in a hierarchy; the arrangement of elements in space (geographical, political, cultural); the trajectory, the process, or the development of a particular movement as well as the causal relationships between elements of interest. All of these visualisations can make use of a variety of forms and media (2D or 3D; static, moving, or interactive; analogue or digital).

Different situations where visualisations can be used

Science can make use of visual communication design in numerous situations. Why we communicate visually depends on the purpose and criteria we set for the project. I like to say that art asks questions (as we can see from artistic explorations into data visualisations or at the intersection of neuroscience and media arts), and that design answers questions. We need them both.

One of the main criteria that must be taken into account in visual communication design is the user. The question must always be asked: to whom are we communicating? Other scientists? Different audiences (educational groups, the general public)? Specific audiences (people with impairments, special needs, inclusivity)? Children? This will always have an impact when we decide to communicate.

The purpose and criteria of communication can be connected to different phases of projects. We can use a few visualisations to explain:

Process:	
sketching	project management, general thinking, brainstorming
animations	time-based media for procedures, projects, step-by-step diagrams, for example, surgical procedures
Ideas:	
graphical abstracts	journals
diagrams	journals
posters	talks, conferences
visual presentations	talks, conferences
scientific illustrations	journals, talks, conferences
editorials and publications	textbooks, magazines, journals, e-books
infographics	
web design, mobile apps	UI, UX
Quantities:	
data visualisation	learning processes, publishing
virtual reality, interactive visualisations	games, learning processes
geometric models, 3D print models, computer modelling, simulation	transformation of medical scans

It is essential that such projects are interdisciplinary and well-planned. Complex projects can only succeed with proper project management in place. Depending on the scope of the project, they should encompass various areas of design, including service design, information design, graphic design, illustration, and photography. These aspects should be complemented by programming, interaction design (HCI), user experience (UX) design, cognitive psychology, search engine optimization analytics, editing, copywriting, proofreading, plain language usage, and performance testing. It is clear that the design process is key to the success of an overall product. Methods and tools that designers use (especially in service and information design) are indispensable, especially for complex projects.

The methods and processes used by design and science are not so different. With some collaboration, it is possible to build cutting-edge interdisciplinary teams for the benefit of both. Both fields also have their own skills and approaches that can cross borders and enrich each other. Herbert Simon claimed that intellectual activity that produces material artifacts is not very different from that which prescribes remedies for a sick patient or prepares a new sales plan for a company. He continues: "Design, so construed, is the core of all professional training; it is the principal mark that distinguishes the professions from the sciences. Schools of engineering, as well as schools of architecture, business, education, law, and medicine, are all centrally concerned with the process of design" (Simon, 1996, p. 111).

The distinctions and similarities between science and design, and the characteristics of both, have been the subject of many detailed discussions in the design and scientific press in the international community, in part because of the influence of technology.

The design process can be roughly divided into eight basic stages (which will be further elaborated below): project content analysis, user analysis, problem definition, design/solution proposal, evaluation, solution improvement, implementation, and impact measurement. In this sense, the design process is not so different from processes in the sciences. Where the difference is most obvious is the approach with which different professionals tackle the process and the criteria that they use for selecting ideas.

Designers often think about multiple ways to approach a problem. They use observational skills, creativity, innovation, and think what the appropriate media would be for a certain project. They make decisions about the visual elements and available variables (clear explanatory illustration, accurate use of colour, colour coding, simplification, hierarchy and visual constants, size and quantity, technical perfection), and about other scenarios that can make the product more active in terms of initiating change (concepts from nudge theory, fun theory, gamification, and also innovative approaches to space or interactivity). Another important element in the design process is testing with iteration, which quickly gives a clear indication about the potential success of a product.

Contemporary concerns and possible scenarios for visualisation in science

The editors of science journals, such as *Nature*, have long promoted the use of visualisation in science, realising that a clear and compelling image is key to science communication. Journal editors are increasingly requesting the submission of a visual abstract along with the text of the article. It might be useful to ask the question: is this really empowering the scientific community?

Research findings show that "articles that have graphical abstracts are beneficial both in terms of views of the article as well as increased activity on social media. In particular, the average annual use of an article is doubled when compared with those without a visual abstract". Therefore, it is no wonder that some publishers offer software to scientists to produce graphical abstracts for their articles and this has quickly become a competitive field. As scientists are pushed into this activity without the necessary knowledge, companies are advertising for-pay products to help scientists "get help". Advertising campaigns for such products appear frequently with slogans such as "Think of a Visual Abstract as the Business card for your Research!" and promotions such as "More than thirty million medical publications on PubMed, more than one million new ones every year: Information overabundance is not a problem of the future. It has become science's biggest threat."

The problem we are confronting is how can scientists with little prior knowledge of visual communication tools, processes, and skills, produce an image that conveys the message of a research paper in a clear and attractive way. To master new tools, no matter how brilliant scientists are, is a lot to demand in addition to their core work. And designers also know that no single solution can work for all projects, and that ready-made recipes are exactly that: recipes.

The British multidisciplinary team DesignScience makes the case in their workshops that scientists cannot be held responsible for all of the problems in science communication because communication is a complex, two-way process. It is not surprising that "scientists get fed up when they do their research, then are told they've got to communicate it. This is understandable when they lack sufficient expertise or support" (Odling-Smee & Kent, 2013).

We might also ask why, if anyone can do it, so many prominent universities offer specialised degrees in scientific illustration, information design, data visualisation, and also combined degrees of science and design in scientific communication. The following are some noteworthy examples: MSc Science Communication and MSc Science Media Production programmes at Imperial College London; scientific illustration programmes in the EU (Zuyd University of Applied Sciences, Maastricht, Netherlands; Ecole Estienne, Paris, France; Forensic Art and Facial Imaging, University of Dundee; Medical Art, Liverpool John Moores University; medical illustration in the US and Canada (Augusta University, University of Illinois at Chicago, Johns Hopkins University School of Medicine, University of Toronto, Rochester Institute of Technology). It is clear that designers and illustrators can contribute to the understanding of science, as they are trained as visual storytellers in specialised programmes. They know how to create interactive experiences that are understandable, illustrate cutting-edge articles, produce animated films, design anatomical models, and illustrate botanical phenomena. Not only artistic skills, but also technological skills, are very important, and usually education in both is needed.

As a result of the specific needs in science communication and worldwide events like the COVID-19 pandemic, new professional niches are emerging. Soon after the pandemic began, when scientists announced an emergency in January 2020, Alissa Eckert (a medical illustrator at the Centers for Disease Control and Prevention, U.S. Department of Health & Human Services, USA) and Dan Higgins were asked for help visualising the coronavirus. Its official name – SARS-CoV-2 – was not something the public understood or were likely to respond to. In contrast, an illustration of the virus was something people were immediately able to understand, at least to a certain degree, but above all, the virus was portrayed as something serious and the drawing attracted attention and influenced the perception of the gravity of the situation. This is a recent example of how collaboration between designers and scientists can have an important effect.

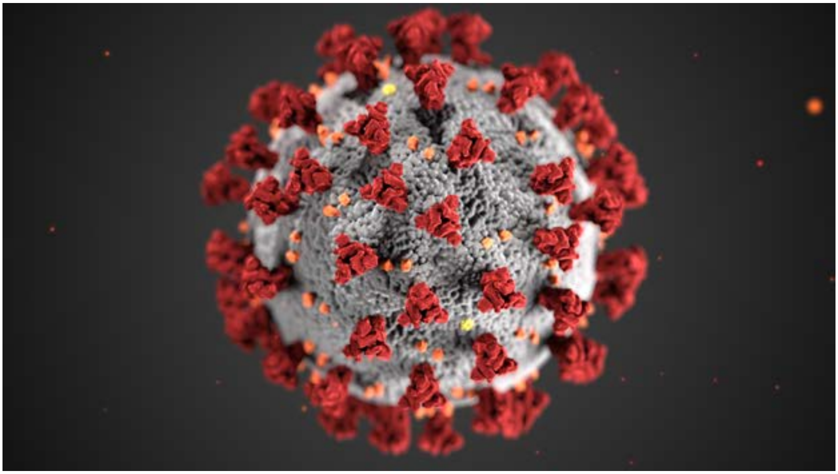

Figure 3: SARS-CoV-2, Alissa Eckert, MSMI; Dan Higgins, MAMS, Centers for Disease Control and Prevention (CDC), retrieved from https://phil.cdc.gov/Details.aspx?pid=23311

It should also be stated that successful designers and illustrators in the field of science communication must have an inherent interest in science. Just as scientists can be highly creative people and can also study design and art, designers can also benefit from a science education if they want to be successful. There is great potential in building bridges between the two fields as the boundaries between the disciplines has become increasingly blurred.

As argued above, design tools that in the past used only by professionals (artists, designers, architects) are now accessible to anyone regardless of their experience and knowledge of visual communication. Although freely available and easily accessible visuals are extensively used, a quick look at presentations and conference posters shows that information is not necessarily presented in a clear, understandable, and functional way, indicating that the benefits of visual language (the increase in the speed of learning, reduction of errors, explanation contextualisation, and complex data visualisation) are not yet fully realised.

We must accept that, similar to science, visual communication design is a complex field, and that passionate and excellent professionals in both science and design are needed for science to get out of the ivory tower and reach the public.

Before scientists attempt to design visuals by themselves, they should go through the following guidelines with a designer in order to determine what is best for a particular job and create a well-defined brief:

- Study examples of good practice and analyse them.
- Think first and conceptualise later.
- Define your audience.
- Define the purpose of your visuals.
- Think about the potential limitations of users (age, colour blindness, special needs, short concentration span).
- It is not about style, but about understanding and clear information.
- Do not succumb to overdesigned, glitzy solutions and decorations; they will not be effective.
- Do not be tempted to search for a solution through the default options of available software.
- Use plain language/clear language concept of writing.
- Less is more.
- Think about media, technology, and technique (comics, video).
- Think about the context of communication.
- Test, test, test as much as possible.
- Iterate and test again.

Conclusion

The abundance of easily accessible data across various platforms shows the need for clear and comprehensible information presentation. This requirement holds true across all disciplines, but it is particularly crucial in scientific research and education where effective communication of new discoveries and concepts is paramount. This paper emphasises the significance of visualization in the field of science, building upon established principles in visual communication design.

Throughout history, visual language has evolved hand in hand with scientific development. Prominent scientists have relied on visualisation to enhance their thinking, streamline their arguments, present information coherently, and disseminate research outcomes. Notably, the seventeenth and eighteenth centuries witnessed the emergence of empirical data tables in mathematics and the advancement of cartography in geography. Pioneers like Priestley and Playfair made ground-breaking contributions to visual representation, with the latter inventing formats still utilised in our daily lives.

Such inventions revolutionised the communication of scientific content, and scientists also used visual methods as tools in the scientific process. For instance, the ISOTYPE system employs graphic symbols to simplify complex quantitative information, and to educate people about diseases, mortality causes, and social-political matters. Furthermore, visual materials have often played a significant role in the research process itself, leading to major discoveries throughout the twentieth century. Visual materials play a crucial role, whether they are generated during the research process, used to illustrate research findings, construct data-driven arguments, or convey scientific facts, processes, and results in a more understandable and visually appealing manner, facilitating knowledge transfer.

In recent decades, the importance of visuals has been recognised and explored in science, with a rise in visually communicated content and the acknowledgement of their ability to enhance research visibility through increased views and engagements on platforms in social media. This expanding utilisation of visual images in science stems from an improved understanding of fundamental aspects of human cognition as well as technological innovations.

In conclusion, the integration of visuals in information presentation is crucial for effective communication in scientific research and education. By employing the myriad of visual tools available and fostering interdisciplinary collaboration with designers, scientists have a greater potential to make a positive impact on society. The current era necessitates interdisciplinary projects that present many challenges to scientists and designers alike but that will provide substantial future benefits.

References

Atzmon, L. (2015). Intelligible design: the origin and visualization of species. *Communication Design*, *3*(2), 142–156. https://doi.org/10.1080/20557132.2016.1199366

Begley, J. (2016). *Every NYT Front Page Since 1852*. [Video]. Vimeo. https://vimeo.com/204951759

Boyd Davis, S. (2017). Early visualisations of historical time. In A. Black, O. Lund & S. Walker (Eds.), *Information design: Research and practice* (pp. 3–22). Routledge.

British Science Association. (2015, December 2). *Science is too important to be left to scientists alone*. British Science Association. https://www.britishscienceassociation.org/news/science-is-too-important-to-just-be-left-to-scientists-alone

Byrne, O. (1847). *The elements of Euclid*. William Pickering.

Compton Crick, F. H. (n.d.) *Pencil sketch of the DNA double helix by Francis Crick. It shows a right-handed helix and the nucleotides of the two anti-parallel strands*. Wellcome Collection. Retrieved November 11, 2022, from https://wellcomecollection.org/works/kmebmktz

Design Science. (n.d.). Retrieved July 8, 2022, from https://www.design-science.org.uk

Evagorou, M., Erduran, S., & Mäntylä, T. (2015). The role of visual representations in scientific practices: From conceptual understanding and knowledge generation to 'seeing' how science works. *International Journal of STEM Education*, *2*(11), 2–13. https://doi.org/10.1186/s40594-015-0024-x

Gilbert, S. (2020, October 7). *Posters that changed the world – in pictures*. The Guardian. https://www.theguardian.com/culture/gallery/2020/oct/07/posters-that-changed-the-world-in-pictures

Goldhill, O. (2018, April 28). *Ludwig Wittgenstein was one of the great 20th-century philosophers. He also invented the emoji*. Quartz. https://qz.com/1261293/ludwig-wittgenstein-was-the-great-philosopher-of-the-20th-century-he-also-invented-the-emoji/

Hatton, C. (2022, July 20). *Hot air apocalypse*. The Critic. https://thecritic.co.uk/hot-air-apocalypse/

Horn, R. E. (1998). *Visual Language: Global Communication for the 21st Century*. MacroVU, Inc.

Imperial College London. (n.d.). *Science Communication Unit MSc Programmes*. Retrieved April 12, 2023, from https://www.imperial.ac.uk/science-communication-unit/

Khan, I. (2015, December 1). *Science: Not just for scientists*. The Guardian Science. https://www.theguardian.com/science/political-science/2015/dec/01/science-not-just-for-scientists

Millar, B. C., & Lim M. (2022). The role of visual abstracts in the dissemination of medical research. *The Ulster Medical Journal*, *91*(2), 67–78.

Mitchell, W. J. T. (1994). *Picture theory*. The University of Chicago Press.

Odling-Smee, A., & Kent, P. (2013, June). *What can design do for science, and science do for design?* Design Science. https://www.design-science.org.uk/news/csf-article-2

Oska S., Lerma E., & Topf, J. (2020). A picture is worth a thousand views: A triple crossover trial of visual abstracts to examine their impact on research dissemination. *J Med Internet Res.*, *22*(12), e22327. https://doi.org/10.2196/22327

Pirtošek, Z. (2016). Umetnost in možgani. *Časopis za kritiko znanosti*, *44*(265), 23–38.

Politzer, T. (2008, November 6). *Vision is our dominant sense*. Brainline. https://www.brainline.org/article/vision-our-dominant-sense

Potter, M. C., Wyble, B., Hagmann C. E., & McCourt, E. S. (2014). Detecting meaning in RSVP at 13 ms per picture. *Attention Perception & Psychophysics*, *76*, 270–279. https://doi.org/10.3758/s13414-013-0605-z

Potter, N. (1980). *What is a designer: Things, places, messages*. Hyphen Press.

Priestley, J. (1765). *A chart of biography*. J. Johnson, St. Paul's Church Yard.

Raworth, K. (2018). *Doughnut economics: Seven ways to think like a 21st-century economist*. Random House Business Books.

Rock, D. (2009). *Your brain at work. Strategies for overcoming distraction, regaining focus, and working smarter all day long*. Harper Collins.

Rocke, A. J. (2010). *Image and reality: Kekulé, Kopp, and the scientific imagination*. University of Chicago Press.

Simon, H. (1996). *The sciences of the artificial*. MIT Press.

Springer Nature Research Solutions. (n.d.) *Visual Abstract*. Retrieved July 8, 2022, from https://solutions.springernature.com/collections/create-impact/products/visual-abstract

Springs S., Baruch J. (2021). Artists on the Research Team: An Interdisciplinary Approach to Team Science, Research Rigor, and Creative Dialogue. *Health Promotion Practice*, 22 (suppl. 1), 83–90.

Stegnar, N. (2021, April 12). *Študentka v stripu 'razčistila' s teorijami zarote*. 24ur. https://www.24ur.com/novice/korona/strip.html

Thermeart (n.d.), *MYND presents sense of healing: AI data sculpture a by Refik Anadol*. https://therme.art/events/sense-of-healing/

Visual Abstract. (n.d.). Retrieved April 18, 2023, from https://www.visual-abstract.com

Walsh, F. (2012, May 16). *The most important photo ever taken?* BBC Health. https://www.bbc.com/news/health-18041884

Wikimedia Commons (n.d.). *Stowage of the British slave ship Brookes under the regulated slave trade act of 1788*. https://en.wikipedia.org/wiki/File:Slaveshipposter.jpg

Zavod Republike Slovenije za šolstvo (2021, November 30). *Nacionalni posvet Vizualna pismenost*. Zavod Republike Slovenije za šolstvo. Retrieved November 11, 2022, from https://www.zrss.si/koledar/nacionalni-posvet-vizualna-pismenost/