The Ecosystem of Science Communication in the Post-Truth Era: Perspectives, Contexts, Dynamics

Edited by
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INTRODUCTION

Marianne Achiam, Dejan Jontes, and Anja Skapin

A Fragmented and Fluctuating Landscape of Science Communication in the Post-Truth Era

Science communication, understood as the social conversation around science, has been gradually expanding and evolving across the globe. As a result, research in science communication has attracted growing attention as well (Bucchi & Trench, 2021; Leßmöllmann, 2020). These developments are reflected in initiatives and programmes at national and international levels all over the world. For instance, in the late 1990s, the US National Science Foundation (NSF) introduced the Broader Impacts Criterion, emphasising the need for researchers to effectively communicate their findings to a broader audience (Roberts, 2009). The NSF also supports research that explores science communication strategies and evaluates its effectiveness. In Brazil, the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) began to support the popularisation and communication of science and technology from 2004 onwards (Massarani & Moreira, 2020), despite the fact that the organisation faced considerable financial challenges and uncertainties under then President Bolsonaro. In South Africa, the Agency for Science and Technology Advancement (SAASTA) was established in 2002 to coordinate public science engagement (Joubert & Mkansi, 2020). In 2008, the Korea Science Foundation, later renamed the Korea Foundation for the Advancement of Science and Creativity, began to offer support for public outreach and engagement with science (Cho & Kim, 2012). And finally, the European Union's (EU) initiatives have progressed from efforts to raise awareness of the European dimension of science (Third Framework Programme, 1990–1994) towards a more specific and directed focus on communication and public engagement in a number of later programmes such as FP6 (2002–2006) and FP7 (2007–2013) (Claessens, 2012). Most recently, the Science with and for Society programmes, particularly the SwafS-19 programme (2018–2020), addressed science communication specifically with funding dedicated to studying and developing the science-society interface (Roche et al., 2021). Following these developments, public communication about science in higher education institutions has diversified, intensified, and partly professionalised (Fürst et al., 2022).

Despite all of this recent activity, science communication remains a disparate and sometimes neglected field. Recent research in Europe indicates that science communication research continues to be interdisciplinary in its origins, including media studies, pedagogy, sociology, psychology, and other disciplines (Gerber et al., 2020; Kessler et al., 2019), and consequently applying a variety of research methodologies to its objects of study (Rauchfleisch & Schäfer, 2018). In addition to the disciplinary orientation, research approaches are also determined by cultural environment, national context, language, and many other factors (Davies et al., 2021; Schiele et al., 2012). A positive perspective on the present state of European science communication research is that it is a "developing field with moving and porous boundaries and intellectually stimulating challenges" (Bucchi & Trench, 2021, p. 1). A more critical description is that the field of science communication research is fragmented and still lacks an interdisciplinary integration of the different research traditions that comprise it (Gerber et al., 2020).

This fragmentation also describes the connection between research and practice. Already in 2010, Priest was concerned with the gap between science communication scholarship and its practice. More than ten years later, this situation persists in the form of a double disconnection in which "neither scholarship nor practice adequately take account of the other side's priorities, needs and possible solutions" (Jensen & Gerber, 2020, p. 2). This discussion is tempered by Bucchi and Trench (2021) who contrast "administrative" research (solving real world problems) with "critical" research (generating theory and concepts), and by Leßmöllmann (2020) who asserts that practical problems do not necessarily lend themselves to scientific inquiry, and, likewise, concepts from research do not necessarily translate into practice. One of the consequences of this theory-practice gap is that there is no generally agreed-upon framework for good practice, except perhaps a general convergence toward engagement models (Davies et al., 2021).

The house is on fire

Today, science communication is confronted with a series of challenges, some new and some a long time in the making. Most explicit is perhaps the need to be able to respond to extraordinary scientific events such as the COVID-19 pandemic, which required scientists to bring their positions to the public sphere with no time for peer review, a situation that often led to argument and frustration on the part of the public. For instance, when public health measures changed in response to the evolving scientific understanding of the virus, these shifts were framed in public discussions as complacency and incompetence, resulting in anger and scepticism (e.g. Capurro et al., 2021; Madvig et al., 2022). This indicates that mainstream deficit and dialogue models may struggle to accommodate science in the making, and that more flexible models are needed to describe and direct the communication of non-routine science (Goulden, 2013; Madvig et al., 2022; Schmid-Petri & Bürger, 2020).

The challenges of the pandemic were exacerbated by the role of social media. Even though in pre-pandemic times many researchers perceived important democratising potentials in social media, these promises have not yet been fulfilled (Jaques et al., 2019; König, 2020). Indeed, the scientific community was less visible on social media than alternative science communicators such as journalists, media, and non-professionals (Weitkamp et al., 2021), indicating that already before the pandemic, scientists struggled to formulate and share strategies for social media use (Fähnrich et al., 2021; König, 2020). In addition, the blurring of boundaries between expert and layman, caused by the dilution of the gatekeeper function (Autzen & Weitkamp, 2020; Petersen et al., 2019; Weitkamp et al., 2021), meant that even before the pandemic, evaluating the validity and credibility of science shared on social media was difficult for non-scientists (Scheufele & Krause, 2019). When COVID-19 struck, these challenges became immediately and urgently apparent. Health authorities faced dilemmas in communicating the fast-changing knowledge about COVID-19 (Madvig et al., 2022). COVID-19 related misinformation was selectively shared on social media (Freiling et al., 2023), and discussions about face masks or vaccinations, for example, became polarised through echo chambers (Modgil et al., 2021). The complexity of the interplay between these actors, drivers, and information streams seemed to preclude simple science communication diagnoses or solutions.

In more general terms, the dominance of social media platforms in the last decade and a half has caused radical audience fragmentation, meaning, among other things, that larger and non-specialised audiences are harder to reach. More importantly, social media platforms have radically changed reading and searching habits which also influences science-related news and information. Algorithmic architecture directs social practices toward being visible and noticed, which requires constant work and influences the consumption and perception of news, science, and social affairs (Jontes et al., 2023). These transformed habits and practices of (mostly younger) audiences have important implications for science communication.

Social media have also enabled the unprecedented circulation of unverified scientific claims. This challenge has gained even more momentum with the rise and popularity of tools of generative artificial intelligence such as ChatGPT. Although the short-term ramifications of generative AI for science communication are still unclear, practitioners and scholars should assess the technology critically in order to both embrace its opportunities and tackle the challenges it presents (Schäfer, 2023). Generative AI is and will continue to be of crucial importance to the practice of and research on science communication.

Climate change represents another and perhaps even more pressing challenge. Since the close of the nineteenth century, scientists have been concerned about the effect that humans might be having on the atmosphere through the emission of carbon dioxide and other greenhouse gases (Trumbo & Shanahan, 2000). The discursive struggles over the meaning of climate change and the problems it entails have been fraught from the very beginning. The notion of climate change has become invested with antagonisms that circulate in a range of social fields including academia, politics, everyday life, and the media (Filimonov & Carpentier, 2022). Furthermore, because climate change is not easily perceivable as it plays out over vast temporal and spatial scales, scientific descriptions of climate change and its effects are often complex and difficult to understand (Schäfer & Schlichting, 2014). As a result, many people learn about climate change almost exclusively from the media.[1]

Finally, although science scepticism and denialism has always existed, shifting values, growing inequality, and increasing polarisation created

1 For example, Romps and Retzinger (2019) focused on the presence or absence of basic scientific facts about climate change in New York Times news articles about this subject. In their analysis of nearly six hundred news articles in The New York Times that cover climate change, they established that, with one exception, basic climate facts appear in such articles with vanishingly small frequencies.

a societal backdrop. The 2016 presidential election in the US, the Brexit referendum (Lewandowsky et al., 2017) in the UK also in 2016, and the 2018 presidential election in Brazil (Reyes-Galindo, 2021) took place against this backdrop and functioned as tipping points to the current post-truth condition.[2] This situation has increased attacks on science and its legitimate impact on public discourse (McIntyre, 2018). Today, when scientists communicate findings that contradict people's beliefs, they may face a deliberate campaign of fake news, misinformation, and disinformation. Even if the scientists' findings are presented clearly and convincingly, they are unlikely to change the minds of people who feel threatened by them (Iyengar & Massey, 2019). Populist politicians, in particular, often use their social media platforms to target science and journalism, arguing that scientists and journalists are part of an "evil elite", deliberately misleading the public by spreading disinformation. While this type of discourse is highly concerning, we still lack empirical evidence on how these accusations affect the public perceptions of scientists and journalists (Egelhofer, 2023, p. 361).

Reinventing science communication?

In response to the socio-cultural transformations described above, calls have been made for a new kind of science communication that renegotiates the role of scientists in the public communication process, as well as the entire figuration of actors, norms and communicative practices involved in science communication (Brüggemann et al., 2020; L'Astorina et al., 2018). This *post-normal science communication* should ensure that science remains an effective safeguard against political or commercial interests in the public sphere, but at the same time, avoid delegating absolute epistemic power to science (cf. Reyes-Galindo, 2021). Accordingly, it must acknowledge that (scientific) knowledge is never absolute, but always constructed at the intersection of individual, culture, society, and organisation. Post-normal science communication should thus be able to handle diversity, complexity, and incompleteness (cf. Dervin, 1998), which necessarily involves dialogue between construction and critique, and between coordinating pieces of evidence, and also the verification of how these elements fit together, which has

2 See also chapter by Marianne Achiam in this volume for further elaboration of the notion of post-truth.

been described in terms of "sensemaking" (Odden & Russ, 2018). Nevertheless, even though dialogue is one of the central approaches of European policy on science communication (Conceição et al., 2020), and even though three recent EU-funded projects (QUEST, RETHINK, CONCISE) worked specifically on designing and implementing new, more dialogical interfaces between science and society, there is still scant evidence of the spontaneous emergence of dialogical, post-normal science communication (Brüggemann et al., 2020; Nicolaisen, 2022). In summary, there is still a need for further reflection and scholarship on research, practice, and stakeholder perspectives (Kupper et al., 2021; Salmon et al., 2017).

It is beyond the scope of this introduction to offer suggestions for what a reinvented science communication approach might look like. Indeed, it is probably overly simplistic to think that a single approach or system of approaches can address the challenges we have outlined in the preceding sections. Nor do we think that these challenges can be ascribed solely to a general shortcoming of science communication. However, we do join our voices with all those who call for approaching science communication as an integrated field in which research and diverse forms of practice are more strongly interconnected (Davies et al., 2021).

Recently, "evidence-based science communication" has been suggested as one way to better connect research and practice. This approach involves the explicit and careful use of evidence from systematic research, combined with professional skills gained from practice, in planning and carrying out science communication (Jensen & Gerber, 2020). However, determining what constitutes satisfactory evidence in science communication is not an easy task. Because science communication is always embedded in broader societal, cultural, and disciplinary contexts (Davies et al., 2021; Nicolaisen et al., 2021; Schiele et al., 2012), and conditioned by variables such as actors, formats, and aims (Bucchi & Trench, 2021), it is difficult for any single researcher or practitioner – however well-informed – to distil generalisable lessons from particular instances. In the words of Bucchi and Trench: "the evidence agenda belies the increasing variety and cultural diversity of science communication practices on a global scale; standard recipes or gold standards can hardly be universally agreed and applied" (2021, p. 5).

Along these lines, Irwin (2021) observes that in science communication, there is no approach that is superior to others in and of itself. Instead, he suggests that "deciding what is appropriate to any particular situation must be a matter for contextual judgement but also recognition of the limitations and strengths of all approaches" (p. 156). Certainly, this was apparent during the COVID-19 crisis when strategic communication was at times prioritised by health officials in order to ensure compliance (Davies, 2022), thereby limiting democratic conversation in what could be considered a non-progressivist direction (Bucchi & Trench, 2021). Rather than attempting to reinvent science communication, then, we suggest that what might be needed is a means to systematically compare, contrast, and even integrate science communication across contexts, disciplines, purposes, and formats. In the final sections of this introduction, we use an ecology metaphor to frame and introduce the chapters in this volume. These chapters emerged from the papers presented by the participants in the Reinventing Science Communication conference that took place in Ljubljana, Slovenia during October 2022. The chapters thus represent a rich sampling of the diversity of science communication practice and scholarship developed by science communication professionals from different countries.

The ecology of science communication

The metaphor of ecology is a useful way to (attempt to) capture the diversity of the conditions that prompt, direct, or govern science communication. In a biological sense, the term ecology refers to the network of relations among organisms at different scales of organisation (Scolari, 2012). Extending this metaphor to science communication means that we can see science communication initiatives as being shaped by their particular ecological *niche*, that is, the specific set of societal, institutional, pedagogical, disciplinary, and modal conditions to which they are "adapted" (to stay with the ecology metaphor). These nested levels collectively describe the *ecology* in which a given science communication initiative is developed and "lives" (Achiam & Marandino, 2014). According to this metaphor, science communication entails more than just the linear translation of complex subject matter into familiar words and phrases (Priest, 2010). It involves the complex and multifaceted evolutionary process whereby scientific knowledge, values, methodology, and/or practices (Davies & Horst, 2016) are adapted to a specific communication niche.

Society

Not surprisingly, pressing societal transformations that have marked recent years inspired many of the contributions to the Reinventing Science Communication conference. These contributions offer theoretical and practical responses to a range of cross-national upheavals. For instance, Marianne Achiam discusses how science centres and museums are in a unique position to enable equitable and democratic dialogue, and thus help address wicked problems such as pandemics, pollution, climate changes, and the biodiversity crisis against a backdrop of increased science scepticism.

The COVID-19 pandemic provided the prompt for Nejc Plohl and Bojan Musil, whose chapter studies the ways evidence-based recommendations were communicated to those sceptical of science during the onset of the pandemic. The communicative style of these recommendations was shaped by freedom-threatening language, choice-enhancing language, message framing, use of narratives, and empathy. The authors conclude that, in order for science communication to be effective, it must take into account and be tailored to the level of individuals' trust in science.

Finally, Tamara Dagen and Melita Kovačević's study how social factors affect distrust in science in four European transition countries (Croatia, Bulgaria, Hungary, Romania), and the effects of this distrust on attitudes about COVID-19 and vaccination in general. César Carrillo-Trueba also takes up the theme of societal information flow. He observes how scientific knowledge often becomes decontextualised as it diffuses through society with the implicit or explicit purpose of serving commercial, national, and sometimes even geopolitical interests. In response, he presents the notion of the "science critic" – a figure in society tasked with contextualising and validating scientific knowledge, and thereby helping to counteract post-normal situations.

Pedagogy

A number of contributions to the volume respond to the ecological level of pedagogy, or what might be called enacted principles for dissemination that transcend disciplines (Achiam & Holmegaard, 2023). Citizen science is a recent and innovative approach that promotes better understanding of research methodology across a range of scientific disciplines. In her contribution, Noemi Crescentini explores the potential of citizen science to bring scientists and non-scientists closer together in the research process. She focuses on the Italian context, drawing on interviews with citizen science professionals in order to generate findings that have the potential to enrich and inform citizen science research and practices in other contexts.

Another contribution focuses on European Researchers Night (ERN), one of the most significant and long-lasting initiatives to bring scientists and other members of society closer together. Authors Afonso Pais, Renata Ramalho, and Ana Sanchez reflect on the insights from their own experience in evaluating the ERN initiative in Portugal, particularly focusing on the feedback of participants. They observe how crucial it is to the success of this initiative that not only research results are communicated, but also the research process itself. This enables participants to understand the benefits of science and its impact on societal well-being. If participants are to become a part of the sensemaking process, the authors argue, the scientist must have a clear goal for their public engagement activities. It thus becomes imperative for scientists to be able to critically reflect on the relation between research, the politics of the field, the institutional context, and their own personal assumptions – in other words, the specific ecology in which research and science emerges.

Discipline

Finally, a number of contributions to the conference, and to this volume, are shaped by the ecological level of specific disciplines, and the conditions and constraints that such disciplines impose on science communication initiatives. Simon Goorney, Federica Beduini, Maria Bondani, Laurentiu Nita, Lydia Sanmartí-Vila, Zeki Can Seskir, Jacob Sherson, and Maria Luisa Chiofalo share their research on how to tell a story about the complex field of quantum technology to make it more understandable and approachable for non-scientists. They develop the culture-scientific storytelling (CSS) theoretical framework and show that learning-by-doing is one of the most effective methods of successfully communicating science to audiences without formal education. The ides of citizens being active participants in the co-construction of knowledge is also a premise of the contribution by Fabiana Battisti and Marco Bruno. The authors analyse comments on social media related to mainstream-video-products on important issues (climate crisis and COVID-19) to make the hypothesis that irony – despite its sometimes controversial nature – can be a tool to deconstruct information clutter and promote awareness about serious topics. Petra Černe Oven takes these realisations a step further in discussing the use of arts-based techniques in science. She focuses on the role and potential of design by which scientists can make use of specific visual material to support arguments and transfer knowledge. Finally, the last chapter is a contribution by Cecilia Lartigue and Aquiles Negrete that takes us to Mexico City where water scarcity is a serious problem. The contribution presents a detective story, in the form of a comic book, that was carefully targeted to specific audiences to disseminate knowledge about water-saving practices. The authors offer compelling arguments about the efficacy of comic books in science communication.

Final remarks

The chapters in this volume provide rich evidence of the increasing variety and cultural diversity of science communication practices across the world (Bucchi & Trench, 2021). Collectively, the science communication initiatives described here exemplify a range of progressive approaches, including dialogue, active engagement, learning-by-doing, and co-construction of knowledge, that in various ways reflect re-inventions or re-imaginings of science communication. In addition, this collection of work points to the inevitable conclusion that dialogue is necessary not just between science and society but also between science communication practitioners and researchers from different ecologies – countries, cultures, institutions and practices. We thus see this volume as a contribution to longitudinal studies of science communication across contexts, disciplines, purposes, and formats. Only in this way can the ecosystem of science communication continue to grow more diverse and self-reflective.

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CONTRIBUTIONS

Marianne Achiam

Post-Normal Science Communication? The Role of Science Centres and Museums in an Uncertain Future

Introduction

The world needs equitable and democratic dialogue. As a global society, we face numerous so-called "wicked problems" related to the unsustainable use of the Earth's resources. The notion of wicked problems, developed by Horst Rittel and Melvin Webber in 1973, describes problems that are ill-defined and rely on value judgments for resolution – and are never truly solved. Today, such problems include climate disruption, the biodiversity crisis, and most recently, the COVID-19 pandemic. The process of tackling these problems is exacerbated by the widespread atmosphere of science scepticism and denialism along with delay tactics and misinformation. From a science communication perspective, the situation can seem overwhelming. Often, it is difficult to see how constructive space can be created for the discussions that are necessary to address the challenges we face.

In this paper, I will consider the role science centres, science and technology museums, natural history museums, and other public science communication institutions (referred to collectively as science museums) can play in creating inclusive spaces to address these challenges. As I discuss in the paper, science museums have the resources, the expertise, and the social presence to counteract mis- and disinformation and to engage a diversity of stakeholders in co-creating responses to the problems we face.

I enter this narrative by first considering the current interface between science and society, and specifically the post-truth phenomena that pervade public discussions in information- and media-rich societies. I briefly discuss historical and societal factors that have intensified this state of affairs, and examine the situation from the specific perspective of science museums. I then turn to the class of global challenges related to sustainability that are considered to be wicked problems, that is, problems that are multifactorial, dynamic, and have no clear resolution (Caron & Serrell, 2009). I discuss how science is evolving to address these wicked problems, and how science museums are uniquely situated to contribute to this work. I conclude by discussing the implications of the ideas presented here for the future practices of science museums.

I want to acknowledge the participants in the Reinventing Science Communication conference (October 13–14, 2022) which took place in Ljubljana, Slovenia. While the ideas I present in this paper are based on the presentation I gave at the conference, the dialogue with my fellow conference participants was instrumental in contextualising, qualifying, and critiquing my claims. I indicate in the paper where I have drawn on conference participants' observations and reflections.

We live in a post-truth era

Historically, objectivity and rationality have been important parts of the self-image of science. The ancient Greeks considered practitioners of science to be disinterested observers of the natural world, and considered science to be the inevitable product of these logical and systematic observations. This perception persisted well into our time. One well-known example can be found in Robert Merton's book *The Sociology of Science*, published in 1942, in which he describes the four normative characteristics that comprise the ethos of (western) science: communism, universalism, disinterestedness, and organised scepticism (or CUDOS). From this perspective, science was considered to advance steadily through critical albeit routine puzzle-solving, while values, attitudes and uncertainties were thought to have little or no influence on the process (Funtowicz & Ravetz, 1993).

In 1962, the philosopher Thomas Kuhn published the book *The Structure of Scientific Revolutions* which introduced the idea of paradigm shifts in science. Kuhn's ideas contradicted the existing image of science. Rather than a smooth and continuous accumulation of scientific facts (or "normal science"), Kuhn described science as periodically undergoing fundamental shifts governed by contingency and debate. These paradigm shifts, Kuhn claimed, were based on competing and irreconcilable differences between views of reality. Accordingly, "objectivity" could not be used as the gauge of scientific truth. Instead, the consensus of the scientific community eventually defined what was taken to be true.

In the following decades, the public image of science underwent further change as many of its traditional assumptions continued to be questioned. In their book *Laboratory Life: The Social Construction of*

Scientific Facts (1979), sociologists Bruno Latour and Steven Woolgar challenged many of the most deeply held intellectual notions about how knowledge is generated by amplifying Kuhn's observation that science constructed facts through social processes in addition to the scientific method (Kofman, 2018; Westrum, 1982). The publication of Latour's subsequent book, *Science in Action: How to Follow Scientists and Engineers through Society* (1987), and his well-known illustration of the two faces of science (Figure 1) helped cement the idea that science is – at times – uncertain, contingent, and changeable, and that there is no meaningful distinction between the social and technical elements of science (de Vrieze, 2017). The public questioning of science culminated in the 1990s with the so-called science wars, a number of academic and public debates that took place mainly in the US. These debates typically occurred between defenders of the authority of science based on objectivity and rationality, and "social constructionists" who claimed that scientific fact was constructed under the influence of social and institutional conditions (Kofman, 2018).

Figure 1: Bruno Latour's illustration of the two faces of science: the mature face (left), gazing back through time represents the established "ready-made science", while the younger face (right) looking towards the future represents the uncertain and changeable "science in the making". Redrawn from Latour (1987)

On one hand, the public questioning of science's social, institutional, and methodological structures has had many positive consequences. The decolonisation movement, as well as the Black Lives Matter and #MeToo protests, have directed much-needed public attention to structural inequities and unsustainable ideologies that pervade industrialised nations and western science. On the other hand, the relativist mindset that resulted from this public reckoning may have helped pave the way for science scepticism and conspiracist ideation to flourish (Kofman, 2018). In fact, Latour himself lamented how his and others' criticism of science created a foundation for anti-scientific thinking and for science denialism in particular (de Vrieze, 2017). Certainly, the ongoing COVID-19 pandemic has demonstrated how mis- and disinformation have driven vaccine hesitancy, health science scepticism, and the uptake of fake cures with tragic consequences in countries across the world (Rocha et al., 2021).

Today, we face a range of challenges related to the ability of ordinary citizens to know what is accurate and reliable information. These challenges include attacks on critical thinking, anti-science policies, science denialism, anti-intellectualism, manipulation, misrepresentation, and organised lying, often by way of appeals to emotion through online media (Braun, 2019). These methods are collectively described in terms of *post-truth*: "relating to or denoting circumstances in which objective facts are less influential in shaping public opinion than appeals to emotion and personal belief" (Oxford Dictionaries, 2016). As I discuss in the following sections, these shifting conversations about science and knowledge have important implications for the contemporary role of science museums.

Science museums and post-truth

Since their origins in the Renaissance, science museums have been closely allied with the scientific endeavour, and have thus reflected contemporary scientific discourse and epistemology (Achiam, 2021; Marandino et al., 2015). This means that these institutions have not always questioned *what* or *why* something counted as science, but rather promoted the versions established in scientific communities. For instance, Evans et al. (2002) describe how specimens in late- nineteenth century museums were displayed in ways that reproduced their "inherent" natural history and taxonomy, while more or less ignoring the perspective of the visitor. In a similar way, Crain et al. (2013) discuss how the prevalent "hands-on" script of science centres reflects ideas of science as objectively discoverable through systematic experimentation, leaving out other viewpoints. In other words, science museums have historically been aligned with the ideas of CUDOS and normal science described above (cf. Braet, 1992).

At first glance, science museums' positivist framing of science seems to provide the foundation for their authority and legitimacy in the public sphere. For instance, in a British study, members of the public felt quite strongly that museums should tell the facts, but refrain from telling the public what to think (Britain Thinks, 2013), while in an international study, Australian and Canadian citizens considered museums' maintenance of an apolitical position to be all-important to securing their trust (Cameron, 2007). In the same way, museum visitors in two US studies indicated that their trust in the museum was predicated on the neutrality of its messaging (American Alliance of Museums, 2021; Jones et al., 2020). For science museums, then, engaging with contentious topics runs the risk of compromising their public image as neutral and value-free, and undermining their trustworthiness (Evans et al., 2020; Navas Iannini & Pedretti, 2022). This state of affairs seems to disqualify science museums from being actors in the present post-truth climate.

However, closer scrutiny reveals that science museums are not (nor have they ever been) neutral. Rather, Cameron (2007) argues that they have succeeded in portraying themselves as apolitical or aperspectual through their institutional practices and purposes. These practices, she writes, have "served as a useful tool to disguise institutional politicality, [and] frame institutional legitimacy and trust with audiences" (p. 340). But as we have discussed elsewhere, this position of feigned neutrality is no longer tenable (Evans et al., 2020). Just as there is an on-going public reckoning with the inequities of western science, many science museums are publicly confronting their own attempts at neutrality (Janes & Grattan, 2019; Janes & Sandell, 2019; Jones et al., 2020). And it is precisely this reckoning that allows museums to play an important role in confronting and counteracting post-truth discourses (Ocampo & Híjar-Chiapa, 2021).

Although much remains to be understood about post-truth phenomena (indeed, this was a point of discussion at the Reinventing Science Communication conference), it seems clear that they cannot simply be addressed by stating the facts or appealing to some universal "truth" (Lewandowsky et al., 2017). Rather, the issues that are subject to post-truth attacks can only partially be answered by science, and this only in broader social and cultural contexts that include a diversity of ways of knowing. This means that empowering citizens to assess post-truth claims means supporting them as they engage in a variety of shared sensemaking situations where science is just one kind of knowledge (Feinstein & Waddington, 2020). And, of course, these are exactly the kinds of situations science museums can create (Achiam et al., 2021) – that is, once they emancipate themselves from the idea of science as the objective truth about the world.

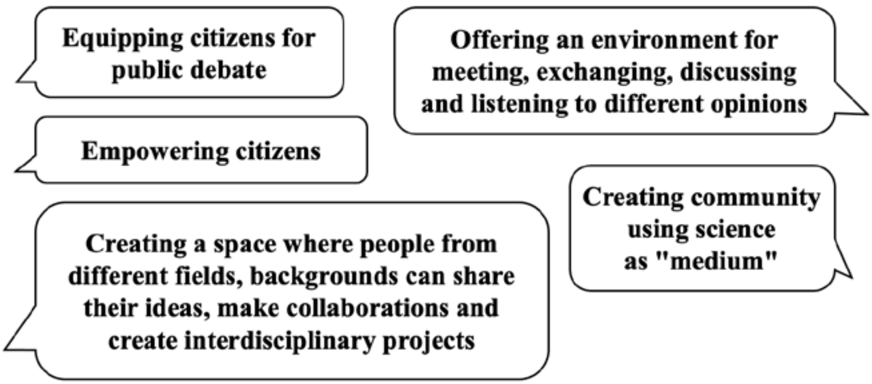

Figure 2: A sample of responses to the question "What is the most important role science museums can play in society?" posed at the Reinventing Science Communication conference in Ljubljana

Participants of the Reinventing Science Communication conference expressed support for this role of science museums (Figure 2) – and indeed progressive museums across the world are already beginning to play this role. Pedretti and Navas Iannini (2020) describe the emergence of a new type of "agential" exhibitions that encourage visitors to critically engage with controversial socio-scientific issues and make informed decisions in ways that prompt changes in their own lives or communities. They offer several compelling examples of such exhibitions, including *Preventing Youth Pregnancy* at the Catavento Museum in São Paulo, Brazil, which promotes responsible decision-making about sexual practices, and *Heureka Goes Crazy* at the science centre in Heureka, Finland, which tackles misunderstandings and prejudices about mental health. Ocampo and Híjar-Chiapa (2021) offer other examples of exhibitions with similar approaches, and specifically discuss the exhibition *Towards an Investigative Aesthetics*, developed by the research agency Forensic Architecture, which raises critical questions about environmental destruction and other issues by engaging visitors in assessing and combining multiple sources of evidence. Finally, the project *Communities for Immunity* (Association of Science and Technology Centers, 2021) supports US museums in engaging vaccine sceptical and hesitant citizens in community discussions about COVID-19 vaccines.

Having briefly discussed the broader socio-cultural backdrop of the post-truth condition, and the challenges and opportunities it poses for science museums, I will now consider some of the more specific problems we face that are related to the unsustainable use of the Earth's resources. As we shall see, scientific practices are evolving in an effort to solve these problems, suggesting a new kind of interface between science and society. I argue that science museums have a unique and critical part to play in this interface.

We face a number of wicked problems

As mentioned above, the COVID-19 pandemic is just one of many complex socio-scientific problems with which we are confronted. We could add to the list anthropogenic climate disruption, the biodiversity crisis, global inequity, food shortages, pollution, and many others. These problems defy the established problem-solving strategies of science and engineering, which have generally focused on "tame" or "benign" problems that are well-defined and whose solutions are clearly recognisable. In contrast, the problems we face now are what Horst Rittel and Melvin Webber termed as "wicked", i.e. they are subject to real-world constraints, meaning that they cannot be definitively described, but require extensive qualification; they cannot be meaningfully addressed in right (or wrong) ways; and they have no definitive and objective solutions (Rittel & Webber, 1973). In their 1973 seminal paper, the authors give examples of contemporary wicked problems that include, for instance, the location of a freeway, the adjustment of a tax rate, the modification of school curricula, or confronting crime. Although these problems are in the domain of social or policy planning, what is clear from these examples is that wicked problems do not remain within the boundaries of scientific disciplines or even within academia, but are deeply entangled with complex natural systems as well as societal structures and institutions. This means that science, with its mechanistic methodology of reducing the world to ever smaller elements that can be understood, controlled, and manipulated, is incapable of providing the solutions (Dürr et al., 2005; Funtowicz & Ravetz, 1993; Rittel & Webber, 1973). Instead, the situation calls for a post-normal science *for* sustainability (Spangenberg, 2011).

Post-normal science distinguishes itself in many ways from the normal science described by Kuhn. In contrast to the value-free, objective accumulation of scientific facts of normal science, post-normal science addresses issues where “facts are uncertain, values in dispute, stakes high, and decisions urgent” (Funtowicz & Ravetz, 1993, p. 744). Its structure, methods, and content are defined by the need to span a range of spatial scales, account for the temporality of the problems it addresses, deal with the complexity of these problems, and acknowledge a diversity of perspectives on what constitutes workable knowledge (Kates et al., 2001). This means that post-normal sustainability science responds to real-world (as opposed to academic) problems (Fang et al., 2018; Kauffman, 2009; Lang et al., 2012), is inter- and transdisciplinary (Brandt et al., 2013; Spangenberg, 2011), has an important temporal dimension (Martens, 2006; Seghezzo, 2009), and involves the participation of stakeholders such as policymakers, citizens, and other knowledge-users in a so-called extended peer community (Block et al., 2018; Craps, 2019; Ravetz, 2006).

Clearly, post-normal science requires a new kind of interface between science and society, not only in the communication of research results but also in the research process itself (Spangenberg, 2011). This challenges the scientific community to shift from one-way "deficit" modes of communication to more relational and reciprocal models (Canfield et al., 2020). These participatory models should support participants' sensemaking about wicked sustainability problems, rather than the more familiar goals of generating enthusiasm for or interest in science (cf. Irwin, 2014). And this is where science museums have a unique and important part to play.

Science museums and wicked problems

Science museums are located in the borderland between science and society, and have gradually been turning toward more participatory and inclusive models of communication (Achiam & Sølberg, 2017). This makes them strong candidates for supporting the new kind of interface between science and society envisioned here. But the role of science museums goes beyond providing the settings and logistics for what we might call post-normal science communication (cf. Brüggemann et al., 2020). I have already briefly discussed how these institutions can offer environments and contexts to support shared sensemaking across different kinds of knowledge. I will now explore these different kinds of knowledge in order to make more radical claims about the communication of wicked sustainability problems and the potential role of science museums. The point of departure for this discussion is Blanche Verlie's assertion that:

> …positioning climate change as a phenomenon to be known primarily through science has led to approaches to public engagement that are highly disengaging, as well as ignoring the emotional pain of those who are already concerned (2022, p. 2).

I would argue that the same assertion could be made for a range of other wicked sustainability problems. Indeed, when humans make sense of the world, they are "multisensorial beings constituted by complex, interrelated cognitive, emotional, affective, corporal conditions" rather than simple information processing machines (Heinrichs, 2019, p. 5). Accordingly, engaging citizens and other stakeholders in experiencing and reflecting on wicked sustainability problems should utilize a range of aesthetic methodologies and imaginative practices that speak to sensory, kinaesthetic, and imaginary ways of knowing (Heinrichs, 2019), rather than perpetuating the mechanistic idea that we humans are somehow separate from the wicked problems we face (Verlie, 2022).

Science museums are ideal places for these kinds of experiences. They have significant expertise in offering immersive experiences through their concentrated reality (Achiam & Sølberg, 2017), stimulating visitors to transcend time and place by imagining things "possibly being so" (Achiam, 2016). Using aesthetic methodologies in science museums is thus about embracing the entanglements and complexity with which wicked sustainability problems come. In this sense, exhibitions and installations become portals for intellectual, emotional, and physical experiences (Reymann, in Bonvik-Stone, 2023), rather than media for the straightforward transfer of information. One compelling example of this is the exhibition *KLIMA X* developed by the Museum of Science and Technology in Oslo. Visitors entering the exhibition were asked to wear rubber boots to wade through the 25 cm of water covering the floor (a scenario mimicking the effects of the polar ice caps melting). The exhibition also included a large ice block that was gradually melting, and simulated thunderstorms and rainfall, giving the visitors the impression of meteorological disturbances (Gorr, 2014). Another example, albeit not from a science museum, is the art installation *Pollution Pods* by Michael Pinsky. In this project, five geodesic domes emulate the atmospheric conditions in Beijing, São Paulo, London, New Delhi, and Norway's Tautra Island by recreating the air using safe chemicals. Visitors navigate the pods, moving through gradually worsening air conditions (Pinsky & Sommer, 2020).

Neither of these exhibitions illustrate sustainability problems in a 1:1 manner. Rather, they are what Ågren (1995) designates as *meta-realistic* exhibitions that "juxtapose objects from reality, in the form of fragments or quotes, in order to stimulate the imagination, suggest thoughts, or hint at ideas" (author's translation, p. 42). Note how these exhibitions collapse space and time in order to offer experiences that otherwise would be invisible and intangible due to their remoteness and incremental development (Pinsky & Sommer, 2020). Exhibitions like these allow us to experience ways of knowing about wicked sustainability problems that are otherwise not available to us.

Another way in which science museums can utilise aesthetic or arts-based approaches in support of a new interface between science and society is by harnessing the ability of artists to imagine the worlds that we want to live in (Reymann in Bonvik-Stone, 2023). This is important, because if we cannot imagine what a sustainable future might look like, it is difficult or even impossible for us to discuss it, consider what it might mean for us, and take on the work of moving toward it (Moser, 2019). Here, science museums can use their expertise to create immersive fictions about sustainable futures that portray complex phenomena and ideas from the perspective of ordinary citizens, without scientific jargon and technicalities. The experience of being immersed in fictional futures can, in turn, move discussions away from the "current technocratic paradigm and towards a more inclusive, participatory process in which citizens can recognise their own experiences and perspectives" (Raven, 2017, p. 165).

A recent example of an exhibition with a future fiction component is *Klimatopia* at the science centre Experimentarium in Copenhagen. In *Klimatopia*, visitors meet three girls from three different futures, corresponding to different scenarios of global warming inspired by the IPCC's Sixth Assessment Report from 2021 (Experimentarium, 2022). Throughout the exhibition, visitors encounter the three-time travellers' personal perspectives on themes such as food, consumer goods, electricity and heating, and transportation. For instance, Aka (from a future with an average global temperature increase of 4.5°C) says: "In my future, we drive around in old clunkers, but it's difficult to find anywhere with petrol, and the roads are terrible. We travel by boat every now and then, when it's possible" (Figure 3).

Figure 3: Detail from the exhibition *Klimatopia* at the science centre Experimentarium. The three girls Aka (in red), Kiiro (in yellow), and Midori (in green) have travelled back in time from three different futures that reflect average global temperature increases of 4.5°C (Aka), 3-3.5°C (Kiiro), and 1.5-2°C (Midori) respectively in the year 2121. The girls are present throughout the exhibition, offering personal narratives of their experiences in relation to a number of everyday themes (transportation in the above image). Photo: M. Achiam

Another relevant example is the public experiment *Climate Garden 2085* in the Botanical Garden at the University of Zürich. Similar to the previous example, *Climate Garden 2085* was based on IPCC scenarios scaled to northeast Switzerland, and included two greenhouses with temperatures corresponding to increases of 2°C and 4°C respectively in the year 2085. By incorporating local plants that people in the region were familiar with and would eat, the project allowed visitors to experience the future climate scenarios in local and personal ways (Schläpfer-Miller, 2021).

These two examples hint at how experiences of the future may function as mirrors of un/desirable realities (Lowe et al., 2006). Their fictional quality allows us to step back from how things are, and mobilise our critical imagination to explore what is plausible, ethical, and desirable (Garforth, 2019). Both *Klimatopia* and *Climate Garden 2085* go beyond just utilising art (in this case, fiction) as a way of increasing public understanding of climate change. They combine art and science in ways that effect change in both the object (the socio-scientific problem of climate change) and the relation between the object and subjects (the visitors). The fictional climate scenarios are not presented as finished or inert information, but rather as uncertain science in the making, allowing visitors to develop their own understandings of climate change that emphasise its local and personal implications (cf. Born & Barry, 2010). In this sense, the visitors become co-producers of knowledge.

Discussion

In the previous sections, I have examined what I see as the important intersections between science, societal discourses, wicked problems, and science museums. I certainly haven't provided an exhaustive exposition of these intersections; my reflections are inevitably conditioned by the sociocultural and academic context in which I am located. Nevertheless, I hope that some of the ideas presented here will stimulate further discussions as indeed they did at the Reinventing Science Communication conference. In the following sections, I will follow up on some of the reflections that arose on that occasion.

Generally speaking, science museums are in a state of flux. From their historical and mainly self-referential functions of preservation, communication, and research, they are gradually shifting their focus to more externally-oriented purposes and abandoning their authoritative stance in favour of more cultural and dialogic approaches to engagement (Achiam & Sølberg, 2017; Black, 2012). On the one hand, some argue that this transition is necessary for museums to remain relevant (Evans et al., 2020; Janes & Sandell, 2019), while, on the other hand, the shift makes some uncomfortable and even seems to contradict what many consider to be the ethos of museums. One measure of this discomfort is the failure of the planned revision in 2019 of the International Council of Museum's (ICOM) official definition of museums. The revision aimed to refine the wording of the existing definition to focus more on social justice, environmental awareness, and political advocacy – focus points that align with what I have discussed in this text. However, the suggested new definition met strong resistance from a variety of figures in the international museum community who criticised it for being overtly political and ignoring the economic and political realities of museums (Noce, 2019; Robinson, 2021). In conclusion, despite the examples I have shared here (and many others) of science museum programmes and exhibitions that transcend the historical museum functions of preservation, communication, and research, it seems the museum community as a whole is not ready to commit to a more radical and critical approach to public engagement. Fortunately, this does not prevent individual museums from devoting themselves to approaches that include critical thinking, sustainability, and equity (Robinson, 2021).

What does it take for science museums to transition to more critical and participatory models of public engagement? Fortunately, progressive practitioners, institutions, and researchers have already shown the way through public consultations and co-creation processes that foreground the socio-cultural meaning of objects, ideas and problems, and de-emphasise a strictly academic viewpoint (see, e.g. the special issue of *Journal of Science Communication* on responsible science communication edited by Achiam et al., 2022). Although opening up science museum practices to the input of non-experts may raise concerns about the loss of scientific authority, I suggest that the experience and lay knowledge of citizens and other stakeholders may be thought of as complements to the scientifically-generated numbers and texts of scientists rather than as replacements for them (cf. Brüggemann et al., 2020).

Finally, it seems reasonable to question whether the suggestions I have given in this paper actually amount to science museums providing citizens and other stakeholders with opportunities to engage in post-normal science. In other words, can science museums and their visitors be considered part of the "extended peer community" that engages with post-normal sustainability science? After all, science museums aren't themselves scientists (although they may be closely allied with them) – so what claims can they make toward the production of scientific knowledge? I suggest two answers to this question.

The first answer emerges from the perspective of scientists and scientific practice. From this perspective, it soon becomes clear that the way that post-normal science is *enacted* can be different from the way it is *prescribed*. Research shows that sustainability scientists don't necessarily welcome dialogical, participatory engagement with extended peer communities, nor do they necessarily incorporate societal concerns in their decisions about what problems to pursue (Achiam, 2023; Brüggemann et al., 2020). This means that post-normal science's objective of public engagement in the research process (Funtowicz & Ravetz, 1993) remains more recommendation than reality. However, I would argue that this gap provides science museums with the opportunity to facilitate border-crossing between science and society, supporting scientists in the challenging task of engaging with their publics by using a variety of formats and modalities (exhibitions, debates, citizen science, etc.) in which science museums have experience and expertise (cf. Evans & Achiam, 2021). In other words, science museums can become the facilitators of the public engagement prescribed by post- normal sustainability science, if scientists themselves are unable to.

The second answer is perhaps more pragmatic. Its point of departure is the definition of post-normal science communication as "communication among relevant actors in the field of science communication who react to post-normal situations" (Brüggemann et al., 2020, p. 3). In other words, if we are relevant actors (for instance, citizens) and we react to post-normal situations (for instance, climate disruption), then we are engaging in post-normal science communication. In this sense, visitors to, for example, *Climate Garden 2085* or the *Pollution Pods*, could be considered members of an extended peer community. Certainly, visitors to both *Climate Garden 2085* and the *Pollution Pods* reacted with concern, sadness, anger, and a desire to take meaningful action in response to their experiences (cf. Pinsky & Sommer, 2020; Schläpfer-Miller, 2021). These findings underscore the point that addressing the wicked sustainability problems we face presents an important imperative to science museums to more carefully consider the multisensorial reality of human life and how it could merge with natural and constructed environments to co-construct atmospheres and resonances (Heinrichs, 2019).

Final remarks

My main argument in this text is that science centres, science and technology museums, natural history museums, and related science communication institutions have an important role to play in creating inclusive spaces to discuss and address wicked sustainability problems. This role requires science museums to transition from an ethos of implicit neutrality to one of explicit subjectivity, and from a practice of passively sharing knowledge to one of actively promoting agency. While many science museums have already made significant advances in this direction, others prefer to stay with their established and – in many cases, publicly sanctioned – functions. As the urgency of the crises we face increases, difficult choices may be inevitable for these institutions. I will leave you, the reader, with a final question: if science museums, which we have trusted for centuries to be the stewards of our scientific heritage, cannot take on this task, who can?

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Nejc Plohl and Bojan Musil

Why and How to Tailor Science Communication to Science Sceptics

Introduction

Data from representative and long-lasting longitudinal studies, such as the General Social Survey, clearly show that we are witnessing the polarisation of trust in science, which means that the differences between individuals and certain subgroups of the population are becoming more prominent than ever before (Gauchat, 2012; Hamilton & Safford, 2021; Lee, 2021). While the idea that these inter-individual differences may be meaningful in explaining decisions made in different contexts is not new, it gained significant traction during the recent COVID-19 pandemic during which low trust in science and scientists was often mentioned as one of the key reasons for the lack of compliance with preventive measures. As a consequence, many world leaders and media outlets now consider building trust in science essential in the battle against COVID-19 and potential future crises. Not surprisingly, the construct of "trust in science" has also attracted the attention of the scientific community. For example, in the last three years (from the beginning of 2020 to the end of 2022), the number of scientific works referring to "trust in science or scientists" is larger than the sum of all such works published before 2020 (418 versus 299 documents indexed in the Scopus database). It is thus clear that researchers are investigating the predictors and outcomes of trust in science as well as the possible solutions that may help to effectively communicate evidence to science sceptics and, over time, build trust in science and scientists.

In this chapter, we will first explain *why* people's trust in science is something that needs to be considered in the context of promoting health and other scientifically supported behaviours. To do so, we synthesise the existing research on trust in science, its determinants, and, especially, potential consequences, with a particular emphasis on health-related outcomes. Second, we will attempt to elaborate *why* distrust in science is linked to low compliance with evidence-based recommendations. In particular, we will draw on the Health Belief Model (Rosenstock, 1974) and the Intertwined Model of Reactance (Dillard & Shen, 2005) to explain the potential mechanisms underlying these associations and clarify why scientific communication should be tailored to science sceptics or individuals who have a distrust of science. Third, we will shift the focus from the question of *why* to the question of *how*, and specifically to *how* messages containing scientific information could be articulated to reduce unintended consequences among science sceptics.

Trust in science: definition, factors, and potential consequences

Trust – across the various disciplines that deal with trust, such as philosophy, economy, and psychology – is generally defined as the intention to accept potential vulnerability based on positive expectations about the intentions of another person or institution (Dirks & Ferrin, 2002; Rousseau et al., 1998). While some authors consider trust to be part of an individual's general disposition, which is, for example, necessary for developing relationships and functioning in the social world (Evans & Krueger, 2009), an alternative or rather complementary view takes into account that trust can vary depending on the person or institution that occupies the role of the trustee. This nuanced approach distinguishes between interpersonal trust (i.e. beliefs regarding the reliability, honesty, and skills of other individuals, which have important implications in close relationships; Larzelere & Huston, 1980; Twenge et al., 2014) and institutional trust (i.e. beliefs regarding the trustworthiness of "generalized others"; Paxton, 1999). The two are not entirely independent. For example, higher institutional trust may promote interpersonal trust among strangers (Spadaro et al., 2020). Institutional trust can be further divided into trust in government (e.g. courts, executives, and law enforcement), trust in other public or quasi-public institutions (e.g. education providers, mass media, and scientists), and trust in the private sector (e.g. employers and providers of goods and services; Bornstein & Tomkins, 2015). It is worth noting that specific forms of trust, such as trust in scientists and trust in government, are not completely uncorrelated, although empirical findings generally reveal that associations between them are relatively weak (e.g. Algan et al., 2021; Capasso et al., 2022). These different forms of trust are presented in Figure 1.

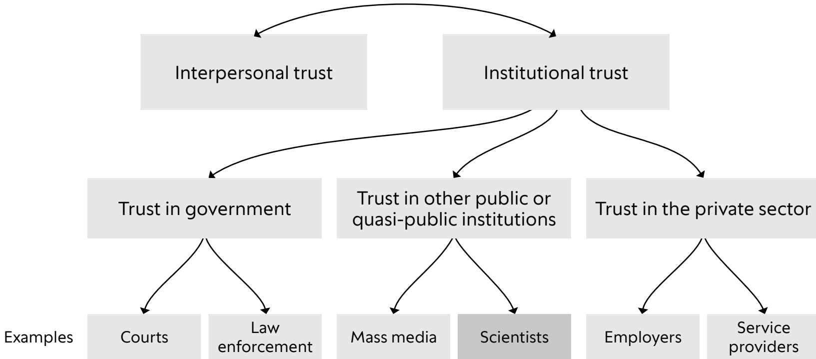

Figure 1: Different forms of trust

Thus, trust in science and scientists is a relatively narrow construct that refers to the belief that scientific research results are an honest and accurate reflection of the work of researchers (Committee on Science Engineering and Public Policy, 2009). People who trust science believe that scientists are honest and reliable, and they believe in the capacity of scientists as providers of information (Wilholt, 2013). In general, this type of trust leads to a greater willingness to accept new information from scientists as trustworthy and relevant.

Factors underlying trust in science

Trust in science varies across cultures (e.g. Algan et al., 2021; Roozenbeek et al., 2020) and among individuals depending on a range of other characteristics. While previous research offers some insight into the factors that affect trust in science, only a few of these factors have been empirically investigated. These factors can be loosely divided into two categories – ideological and cognitive factors.

In terms of ideological factors, we first note that research shows that higher political conservatism is consistently linked with lower trust in science and scientists (Nadelson et al., 2014; Nadelson & Hardy, 2015; Plohl & Musil, 2021, 2023; Rutjens et al., 2018b). Interestingly, this link was only established in recent decades, perhaps in part due to the recent rise of prominent conservative political figures who publicly devalue the importance (and truth) of scientific evidence (Rosenbaum, 2020). Second, research consistently shows that people who are more religious are less likely to trust science (Chan, 2018; Johnson et al., 2015; Plohl & Musil, 2021, 2023; Rutjens et al., 2018a, 2018b). In contrast to the association between science and political conservatism which is relatively recent, the relationship between science and religion has always been tense because the two approaches offer different and often contradictory answers to a range of fundamental life questions. Science and religion, because they in some sense challenge each other's authority, rarely coexist in the same people, and particularly not in religious believers who are highly dogmatic or orthodox (Rutjens et al., 2018a). Third, recent studies emphasise the important role of conspiracy ideation (or belief in conspiracy theories) which is defined as an unnecessary reliance on conspiracy theories in cases where other explanations are far more plausible – for example, the belief that the COVID-19 pandemic was caused by 5G technology (Aaronovitch, 2009; Freeman et al., 2020). Research generally shows that those with higher levels of conspiracy ideation also tend to have less trust in science (Lewandowsky et al., 2013; Rutjens & Lee, 2020), which is not surprising. People who are prone to endorsing conspiracy theories often see scientists as members of a group that colludes with other powerful groups, distorting results and spreading beliefs that benefit such groups (Rutjens et al., 2018a).

The most studied cognitive factor is education level. Education is considered a cognitive, as opposed to ideological, factor mainly due to the idea that trust in science may require some forms of knowledge regarding the scientific process, and this knowledge is generally attained in the educational system (Rutjens et al., 2018a). While some studies have found education to be positively associated with trust in science and similar variables (Hornsey et al., 2021; Morgan et al., 2018; Nadelson et al., 2014), other studies have found practically no association between the variables (Plohl & Musil, 2021, 2023). A recent article sheds some light on why these findings are mixed. Drawing on a sample of more than one-hundred thousand participants from various countries, the researchers found that the positive association between education and trust in science depends on social context. In particular, an association between education and trust in science and scientists was practically non-existent in highly corrupt countries (Alper et al., 2023). While other cognitive factors have not been extensively researched, a recent study by our research group tested the incremental value of cognitive reflectiveness (i.e. the degree to which an individual is capable of intuition inhibition and deliberate thinking; Toplak et al., 2011) and intellectual humility (i.e. non-threatening awareness of one's own intellectual fallibility; Krumrei-Mancuso & Rouse, 2016) in predicting trust in science, after controlling for other known factors of trust in science. We found that an aspect of intellectual humility, openness to revising one's viewpoint, emerged as one of the key predictors of trust in science (Plohl & Musil, 2023).

Potential consequences of low trust in science

Low trust in science can reduce public support and funding for science, which decreases the probability of scientific discoveries and negatively impacts social well-being (Muñoz et al., 2012). On the individual level, it may decrease a person's motivation to learn about scientific findings or may even cause the complete rejection of scientific findings (Gauchat, 2012). This can be particularly problematic in the case of complex topics that are poorly understood by the general public, as poor comprehension and confusion often encourage people to rely on intuitive feelings of trust or distrust (Scientific American, 2010). Moreover, trust in science is thought to play a vital role in how highly emotional and personally relevant topics are perceived, including areas such as health and climate change (Nadelson et al., 2014).

Since empirical research on the potential outcomes of the level of trust or distrust in science only emerged during the COVID-19 pandemic, trust in science-based decision-making research is for the time being somewhat limited to the area of health and, even more specifically, COVID-19.

There is now convincing evidence that people's trust or distrust in science had a critical role in determining their compliance with COVID-19-related guidelines and their decisions regarding vaccination. Our study (Plohl & Musil, 2021), which tested a structural model including various potential predictors of compliance with COVID-19 guidelines and was conducted during the first months of the pandemic, was one of the first studies to empirically link trust in science to individual responses during the COVID-19 pandemic, and specifically to compliance with prevention guidelines (e.g. regular handwashing, avoiding social gatherings, and staying home when sick). The results showed that perceived risk associated with COVID-19 and people's level of trust in science independently predicted their compliance with COVID-19 guidelines. Moreover, trust in science played the role of a mediator between more general socio-demographic variables (political conservatism, religious orthodoxy, conspiracy ideation, intellectual curiosity) and compliance with the guidelines. The socio-demographic variables contributed to compliance only indirectly via trust in science (Plohl & Musil, 2021). Similarly, our follow-up study showed that trust in science was again positively associated with compliance with COVID-19 guidelines, and also with the intention to get vaccinated against COVID-19. In fact, of all the included variables (scientific literacy, health literacy, education level, religiosity, political conservatism, conspiracy ideation), trust in science was the strongest correlate of both COVID-19-related outcomes (Plohl & Musil, 2022).

Studies from other researchers mostly support these conclusions. For example, the important role of trust in science in determining compliance with COVID-19 prevention guidelines and COVID-19 vaccination also emerged in two large cross-cultural studies (Pagliaro et al., 2021; Roozenbeek et al., 2020). A recent longitudinal study conducted on representative samples from twelve countries showed that trust in science was the key driver of individual support for and compliance with COVID-19-related preventive measures and favourable attitudes toward vaccination. The key role of trust in science has been further supported by experimental data (Algan et al., 2021).

The potential outcomes of trust or distrust in science most likely extend to other health behaviours and beyond. First, a few studies (albeit limited) conducted prior to the COVID-19 pandemic highlighted the role of trust in science in explaining vaccination decisions in the context of HPV and other viruses (Keelan et al., 2010; Yaqub et al., 2014). The notion that trust in science could shape other health-related decisions is also supported by our recent study, which showed that trust in science correlates with a range of recommended health-related behaviours, including healthy eating, physical activity, constructive stress management, and general health responsibility (Plohl & Musil, 2022). Second, although empirical research is lacking, we argue that the important role of trust in science may also be carried over to how people deal with climate change. Similar to the sphere of health, the discussion of climate change is riddled with conflicting information, and levels of trust potentially determine what we believe and take into account when shaping our behaviours (Brewer & Ley, 2013). In their recent paper, Perkins et al. (2021) specifically point out that the conclusions drawn from social behaviour during the COVID-19 pandemic could be used to prepare for dealing with climate change, with one of the key lessons being the importance of trust in science. They argue that ignoring scientific findings, overestimating one's own knowledge (the Dunning-Kruger effect), and acting according to one's own distorted perceptions and interests have become major obstacles to tackling climate change, and that successfully dealing with current and future situations arising from this problem will only be possible if trust in and reliance on science and scientists is strengthened. Ojala's (2021) arguments are similar, emphasising the importance of considering trust in science when studying climate engagement.

Integrating trust in science into broader models

Research consistently shows that distrust in science decreases the likelihood of adopting COVID-19-related health recommendations. Moreover, while evidence is scarce, the existing studies suggest that such attitudes and responses likely apply to other evidence-based recommendations as well. However, at the moment, there are no comprehensive models explaining the mechanisms underlying these associations. In other words, trust in science is not yet integrated into broader models aimed at explaining people's decisions in the health (persuasion) context. In this section, we explain how trust in science could be integrated into two well-known social psychological models, namely the Health Belief Model (Rosenstock, 1974) and the Intertwined Model of Reactance (Dillard & Shen, 2005).

The Health Belief Model is a widely cited and empirically supported health behaviour change model that aims to explain and predict health behaviour of individuals. The model proposes that the likelihood of engaging in health-promoting behaviour is determined by four factors.

The first two – perceived susceptibility to a condition (i.e. subjective assessment of the risk of developing a health-related problem) and perceived severity of contracting an illness (i.e. subjective assessment of the severity of a health-related problem) – describe the personal risks perceived by an individual. The remaining two – perceived benefits of recommended behaviour (i.e. subjective assessment of the value of engaging in a health-promoting behaviour) and perceived barriers to undertaking the recommended behaviour (i.e. subjective assessment of the obstacles to changing behaviour) – in contrast, describe the perceived value of engaging in a health-promoting behaviour. According to the model, these four central components are influenced by so-called modifying factors, such as personality and knowledge, as well as cues to action, such as public health campaigns (Janz & Becker, 1984; Rosenstock, 1974).

While the Health Belief Model does not explicitly mention trust in science, we argue that it can, first, be understood as one of the critical modifying variables (i.e. variables that facilitate or hinder constructive health behaviour). Theoretically, trust in science may be related to all four central components of the Health Belief Model, as people who trust science may be more likely to believe scientists' warnings about the spread and seriousness of diseases as well as their evidence regarding the effectiveness and safety of countermeasures such as vaccination. Such claims have already been supported in studies that found positive correlations between trust in science and perceived COVID-19 risks (e.g. Plohl & Musil, 2021). Second, trust in science may interact with cues to actions in determining whether people will choose to act in health-promoting ways. In other words, trust in science may determine whether cues to action are successful in persuading people to perform recommended behaviours; in cases when trust is low, cues to action may be ignored or actively disregarded. This idea can be further elaborated via the inclusion of trust in science in the psychological reactance theory framework.

The role of trust in science in psychological reactance theory

The psychological reactance theory was established to explain the motivational state that causes people to seek ways of regaining their sense of freedom after being faced with something that subjectively threatens it (Brehm, 1966; Rosenberg & Siegel, 2018). The theory can be applied in various contexts, including health persuasion, where it sheds light on why persuasive messages can sometimes be ineffective and lead to unintended outcomes. This is explained in an elaborate way in the Intertwined Process Model (Dillard & Shen, 2005). The model posits that when persuasion poses a threat to people's freedom, a reaction in terms of negative cognitions (counterarguments) and emotions (anger) will occur, leading to more negative attitudes toward the persuasive message or its content, and in turn reducing the likelihood of the desired behaviour (Dillard & Shen, 2005; Rains, 2013).

The Intertwined Process Model mainly emphasises that characteristics of message (stimulus) determine whether reactance will occur and to what extent. On the other hand, research on individual characteristics associated with state reactance is less developed. Early ideas about such characteristics contributed to the emergence of a construct called dispositional reactance (sometimes also referred to as reactance proneness), which is defined as a person's trait propensity to experience psychological reactance (Hong & Faedda, 1996; Shen & Dillard, 2005). Previous studies show that people with high dispositional reactance are more likely to experience reactance after exposure to persuasive messages than people with low dispositional reactance (e.g. LaVoie et al., 2017). However, the concept of dispositional reactance, which is general in nature, does not consider nuanced but also important aspects, such as the source of the message and the recipient's perception of this specific source.

Complementing dispositional reactance with variables such as trust may thus improve our understanding of state reactance. This is supported by previous studies which found that the more participants perceived the source as trustworthy, the less likely it was for state reactance to occur (Song et al., 2018). While there are several specific types of trust, trust in science and scientists may be particularly important in the context of communicating evidence-based (health) recommendations, because scientists represent the ultimate source of such recommendations. As such, trust in science could influence the extent to which messages lead to psychological reactance and further moderate the association between message characteristics and state reactance (*Figure 2*).

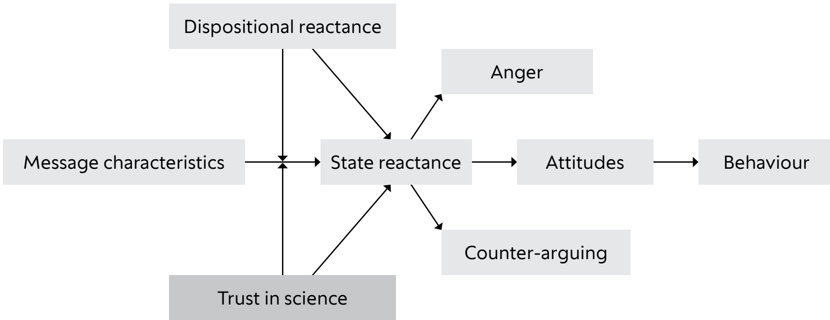

Figure 2: The role of trust in science in the Intertwined Process Model

We investigated this idea in our recent work (Plohl & Musil, under review). In this study, individuals were presented with either high- or low-threat messages promoting either mask-wearing to reduce the spread of COVID-19 or regular physical activity. First, the results showed that, regardless of the topic, psychological reactance and the associated outcomes (i.e. negative attitudes and low behavioural intentions) are more likely to occur after exposure to high-threat messages (as compared to low-threat messages). We call this the main effect of message characteristics. Second, we found that, compared to those who trust science, people who are distrustful of science experienced more intensive state reactance, more negative attitudes, and lower behavioural intentions after exposure to COVID-19 messages, but not after exposure to physical activity messages. We call this the main effect of trust in science, which appeared only in the case of COVID-19 messages. Second, we found that trust in science interacts with message characteristics in determining reactance and other message-related outcomes in the case of COVID-19 messages, but not in the case of physical activity messages. We call this the interaction effect. All of the conclusions remain the same when controlling for the role of dispositional reactance, highlighting that the role of recipients' trust in science goes beyond the role of the general propensity to experience psychological reactance. However, the results also reveal that the role of trust in science may be somewhat nuanced. The study reiterated that, as noted in section 2.2., trust in science seems to be particularly important in the case of poorly understood and highly emotional phenomena (such as the COVID-19 pandemic) that are characterised by a high amount of misinformation and strong emotional responses (Chou & Budenz, 2020; Shahi et al., 2021; The Lancet Infectious Diseases, 2020).

In sum, the findings of our unpublished study propose that when it comes to delicate issues like COVID-19, people who have less trust in science should be approached with public health messages that avoid threatening their freedoms. Messages crafted in such a way appear to generate less state reactance and encourage more willingness to adopt the recommended behaviours among people who distrust science and do not adversely affect those who do trust it. In the long term, such careful messaging may also contribute to increased trust in science among otherwise distrustful people (Plohl & Musil, under review).

From why to how: constructing scientific messages for distrustful recipients

Previous literature shows that several message features can make a message less freedom-threatening and thus diminish reactance, which may be especially important when communicating evidence-based guidelines to those sceptical of science. We will describe five of these features: freedom-threatening language, choice-enhancing language, gain-loss message framing, using narratives, and empathy (for an exhaustive review of message features associated with reactance, see Reynolds-Tylus, 2019b).

The first important message feature associated with state reactance is freedom-threatening language (sometimes also called controlling, dogmatic, domineering, or forceful language). This term refers to language that explicitly limits the autonomy of recipients by using directive phrases like "you must", "it is impossible to deny", and "stop the denial" (Rains, 2013; Reynolds-Tylus, 2019b). To illustrate public health messages containing high levels of freedom-threatening language, we quote a sample text used in the study by Dillard and Shen (2005, pp. 152): "As any sensible person can see, there is really no choice when it comes to flossing: You simply have to do it. In fact, the scientific evidence showing a link between gum disease and failure to floss is so overwhelming that only a fool would possibly argue with it... Flossing: It's easy. Do it because you have to! Set a goal for yourself to start to floss every day during the next week (starting today)!" Previous research conducted in different health-related contexts (e.g. drug abuse, sunscreen usage, tobacco use) and aimed at various populations (e.g. adolescents, college students, and adults), consistently suggests that high freedom-threatening language (as compared to low freedom-threatening language) increases freedom threat and reactance, making public health messages containing such language less effective in achieving desired outcomes (Reynolds-Tylus, 2019b). The importance of using more implicit language was also recently demonstrated in the context of COVID-19 messages. For example, a study by Ma and Miller (2022) investigated the effects of freedom-threatening language on reactions to COVID-19 vaccination promotion messages. Results showed that persuasion was less successful when high freedom-threatening language (as opposed to low freedom-threatening language) was used. More specifically, high levels of freedom-threatening language led to a greater freedom threat, state reactance, source derogation, and generally less positive attitudes toward the message. The authors hence concluded that high freedom-threatening language should be avoided when promoting COVID-19 vaccination. Similar results were also obtained outside of the health context, for example in studies promoting energy conservation (Reynolds-Tylus, 2019a).

A language feature that is consistently linked to lower state reactance is more choice-enhancing language. Unlike freedom-threatening language, choice-enhancing language is generally linked to reduced reactance arousal (Reynolds-Tylus, 2019b; Rosenberg & Siegel, 2018). Such language can be integrated into messages in several ways. One option is explicitly providing behavioural alternatives in messages (e.g. providing two recommended responses instead of one or suggesting a longer list of possible actions and enabling message participants to choose the preferred action; Reynolds-Tylus, 2019b). However, the most-studied type of choice-enhancing language are pre-emptive scripts and restoration postscripts – short statements presented before (in the case of pre-emptive scripts) or at the end of a message (in the case of restoration postscripts) that reinforce the perception of autonomy by emphasising that the decision to comply with the message recommendations is the recipient's choice (Reynolds-Tylus, 2019b; Richards et al., 2020). Examples include statements such as: "The choice is yours", "You are free to decide for yourself", and "It's up to you" (Miller et al., 2007; Richards et al., 2020). Several studies have concluded that adding pre-emptive scripts and restoration postscripts can reduce freedom threat and reactance in and outside of the health context (Bessarabova et al., 2013, 2017; Richards & Larsen, 2017). A recent study by Richards and colleagues (2020) investigated the relative effectiveness of two choice-enhancing strategies – pre-emptive scripts and restoration postscripts. Using an experimental design that varied freedom-threatening language, reactance-mitigation strategies, and health-related topics, the authors found that both pre-emptive scripts and restoration postscripts reduced state reactance which, in the next phase, also influenced attitude changes and behavioural intentions.

Both freedom-threatening language and choice-enhancing language using restoration postscripts were manipulated in our recent study (described in section 3.1) to create high and low threat messages, with results showing that people feel significantly less reactance after exposure to low threat COVID-19 messages. Similarities and differences between high and low threat messages promoting mask-wearing to reduce the spread of COVID-19 are outlined in Figure 3.

	High threat message	**Low threat message**
Similarities	Identical design. Identical insight: "Wearing face masks reduces the risk of infection by approximately 50%." Identical source: *The Science for Health Initiative*. Identical references supporting the scientific insight.	
Manipulation of freedom-threatening language	"STOP THE SPREAD OF COVID-19 AMONG THE MOST VULNERABLE!" "You must wear a face mask when visiting healthcare facilities."	"STOP THE SPREAD OF COVID-19 AMONG THE MOST VULNERABLE" "Please wear a face mask when visiting healthcare facilities."
Manipulation of choice-enhancing language	At the end of the message: "Masks are MANDATORY!"	At the end of the message: "Your decision matters."

Figure 3: Freedom-threatening and choice-enhancing language

Other ways of mitigating state reactance include gain-loss message framing, using narratives, and evoking state empathy. The literature on message framing generally distinguishes gain-framed messages that emphasise the advantages of adopting the recommended behaviours (e.g. “If you decide to get tested for HIV, you may feel the peace of mind that comes with knowing about your health.”), and loss-framed messages that emphasise the disadvantages of failing to adopt the recommended behaviour (e.g. “If you don’t get tested for HIV, you may feel more anxious because you will wonder if you are ill.”; Apanovitch et al., 2003; Reynolds-Tylus, 2019b; Rothman & Salovey, 1997). While findings are not conclusive, multiple studies report that loss-framed messages elicit a greater threat to freedom and reactance. For example, Cho and Sands (2011) found that when advocating sun safety behaviour among adolescents, a loss-frame message produced a greater perceived threat to freedom and hence anger. Moreover, a web-based experiment by Shen (2015) showed that loss-frame messages increased reactance, while gain-frame messages decreased psychological reactance to skin cancer-related messages. Similar results were also obtained in the COVID-19 context. A large cross-cultural experimental study with more than fifteen thousand participants from eighty-four countries reports that framing COVID-19 messages in terms of potential losses (compared to potential gains) increased self-reported anxiety among recipients (Dorison et al., 2022).

The next tool is narrative communication, broadly defined as providing information through stories (Kreuter et al., 2007), which is being increasingly recognised as an alternative way of communicating that can alleviate some of the problems of more traditional scientific communication such as poor comprehension, low engagement, and low persuasiveness (Dahlstrom, 2014; Plohl et al., 2019). Another benefit of narrative communication may also be lower reactance, perhaps due to the persuasive intent being more implicit (Reynolds-Tylus, 2019b). For example, Gardner and Leshner (2016) investigated whether communicating diabetes self-care messages via stories can reduce psychological reactance and associated negative outcomes. They constructed various print messages with narrative stimuli; for example, people diagnosed with diabetes talking about their experiences and articulating the recommendations. The authors found that narratives led to a lower perceived threat to freedom, less psychological reactance (both anger and counterarguing), more positive attitudes towards the message and the promoted behaviours, and higher behavioural intentions to comply with recommendations.

Narrative communication is also linked with another message feature that has previously been associated with lower psychological reactance, namely empathy – a state that can have affective (i.e. recognising, understanding, and experiencing the emotions that the characters experience and express in the narrative), cognitive (i.e. understanding, acknowledging, and adopting the characters' viewpoints), and associative aspects (i.e. experiencing reception and interpretation of the narrative from the inside, as if the events were happening to the recipients; Reynolds-Tylus, 2019b; Shen, 2011). Empathy-arousing message features specifically include vividness (e.g. concrete, visually appealing pictures in the message), realism (plausible narratives or narratives based on real stories), elements of pain and suffering (e.g. a character struggling in a difficult situation), and emotion expression (i.e. characters expressing their emotions explicitly and strongly; Shen, 2019). Previous research shows that experiencing state empathy (which can be a result of empathy-inducing message features) may reduce psychological reactance, which in turn leads to positive persuasive outcomes (Shen, 2010, 2011).

Conclusion

To summarise, this paper demonstrates evidence that trust in science is one of the crucial drivers of health-related decisions with distrustful people presenting a high-risk group that is less likely to comply with evidence-based recommendations. It is possible that such responses can be generalised to other areas. For example, trust in science may also be an important determinant of pro-environmental behaviour, and behaviours in other complex, emotional, and highly personally relevant contexts. Those who are – in addition to their low trust in science – characterised by being more politically conservative, religious, prone to conspiracy ideation, and low in openness to revising their viewpoint are more likely to disregard information coming from scientists and make decisions that can be harmful to them, others, or the environment. Therefore, it is important to explore how this population could be effectively addressed with science communication.

Some guidance for this can be found within the framework of psychological reactance theory, which posits that messages threatening people's subjective freedom lead to stronger negative cognitive-emotional responses and decrease the likelihood of complying with the communicated guidelines. Individuals differ in their proneness to experience reactance. As shown by our recent study, low trust in science increases the risk of experiencing reactance to messages describing contentious issues, such as COVID-19. However, the study also shows that this only occurs in the case of threatening messages, whereas responses to more implicit messages are comparable to those who trust science more. Hence, science communicators could benefit from tailoring communication based on trust in science and delivering low-threat messages to this audience group. This may be achieved by using low freedom-threatening language, features of choice-enhancing language (e.g. restoration postscripts), gain-framed messages, narrative communication, and empathy-arousing features. We believe that such careful messaging represents an essential step toward making science more accessible to those who may need it the most and building a resilient society capable of coping with diverse challenges.

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Tamara Dagen and Melita Kovačević

Science Communication in Transition Countries: The Thin Line between Trust and Distrust in Science

Introduction

The last wave of globalisation accelerated at the beginning of the twenty-first century and significantly changed global communication. The development of new technologies and digitalisation impacted the world of science, encouraging researchers, universities, and scientific institutions to put greater effort into the presentation and communication of scientific work and its results to the broader public. The complex and multifaceted process of mediatisation – in which media technologies, practices, and values became deeply integrated into social structures and impacted the behaviour of individuals – facilitated communication, access to information, and opportunities for self-expression. In addition, internationalisation, which became increasingly important, began to play an integral role in institutional strategies, encouraging and fostering the connecting and networking of researchers worldwide. In this new context, continuous communication of scientific results outside the academic environment has become an urgent necessity. Because of this, various scientific communities, institutions, and individuals have developed and implemented a range of different science communication models and practices.

During the second decade of the twenty-first century as the need for the development of new strategies for science communication and the transfer of scientific knowledge to the public began to grow, the trend of increasing doubt in science also became evident. This trend grew covertly at first, mostly related to topics such as vaccination, genetically modified organisms (GMOs), climate change, and global warming, but its peak was experienced during the COVID-19 pandemic. The Internet and the emergence of social networks and their rapid development created a new virtual debate space for questioning science and scientific results in the international community. As a result, individuals around the globe were able to share online posts and opinions that often contradicted established scientific knowledge.

In this perspective paper, we address the issue of science communication using the example of the COVID-19 pandemic. We base our conclusions on publicly available data. By using descriptive statistical analysis, we indicate several social factors that may have increased distrust in science during the pandemic, looking specifically at four transition countries (Croatia, Bulgaria, Hungary, and Romania), regardless of the level of education or previous experience of their populations.

Our analysis relies on two premises: (1) Continuous scientific communication and the presence and popularisation of science in the media and among the broader public leads to its demystification and contributes to a better understanding of scientific topics in the population at large; (2) These activities consequently cause the growth of trust in science in general. In contrast, rare or non-existent communication of science and research achievements in the media and among the public prior to the pandemic, as well as several other socio-political characteristics of transition countries, might correlate with the level of distrust in science and how the public responds to recommendations based on scientific knowledge during acute situations such as the COVID-19 crisis.

In the first section, we briefly address science communication definitions and models based on a review of the literature. In the next section, we present our observations of science communication in the context of European higher education, research, and mediatisation. In the third section, we focus on science communication in transition countries. In particular, we observe the effects of four socio-economic factors that might have an important impact on people's attitudes about science and the level of trust in science in various national contexts (level of education, economic growth and percentage of GDP, security and economic stability of the country, and the presence of corruption). After presenting the observed phenomena related to (dis)trust in science in the context of the COVID-19 pandemic, based on descriptive statistical analysis, we offer some thoughts on the future of science communication and the relevance of its more robust development in transition countries.

Science communication – definition and models

Science communication, as well as more recent models that began to be developed in the last few decades, is understood differently within the academic community than the professional public. As a result, there is a gap in defining science communication and other related concepts (e.g. Public Awareness of Science – PAS, Public Understanding of Science – PUS, Scientific Literacy – SL, Scientific Culture – SC, Public Engagement with Science – PES, etc.) in the literature and in practice.

The importance of science communication significantly increased in 1985 when the Royal Society in London established an ad hoc group chaired by Walter Bodmer that created a report titled “The Public Understanding of Science” (López Pérez & Olvera-Lobo, 2017). The aim of the report was to provide recommendation to help governments, schools, universities, the media, and scientists promote science and scientific phenomena through joint actions and activities, thus facilitating the creation of a “scientifically literate” population. The Royal Society initiative become a milestone for the accelerated development of science communication, which has become increasingly relevant in recent years.

There are different approaches to defining science communication in the literature (e.g. Bryant, 2003; Treise & Weigold, 2002; Trench & Bucchi, 2010; Metcalfe, 2019; etc.). In this paper, we follow the widely recognised AEIOU definition by Burns at al. (2003), according to which:

science communication (SciCom) might be defined as the use of appropriate skills, media, activities, and dialogue to produce one or more of the following personal responses to science (the vowel analogy):

- Awareness, including familiarity with new aspects of science,
- Enjoyment or other affective responses, e.g. appreciating science as entertainment or art,
- Interest, as evidenced by voluntary involvement with science or its communication,
- Opinions, the forming, reforming, or confirming of science-related attitudes,
- Understanding of science, its content, processes, and social factors (p. 191).

Science communication developed under the auspices of the academic discipline of communication. Over the decades, it passed through significant transformations. Although the literature offers various approaches to different models of science communication (e.g. Trench & Junker, 2001; Trench, 2008; Höppner, 2009; Kurath & Gisler, 2009;

Horst & Michael, 2011; Stocklmayer, 2013; Metcalfe, 2019; etc.), the direction of communication in the process has changed. One-way communication involving the active role of the sender has been substituted with two-way communication between the sender and the receiver. A dialogue model, implying the active role of both sender and receiver, is predominant today.

In the European context, the dialogue model was upgraded to include the active participation and involvement of various target groups in the process of science communication. This change has been the result of various policies and programmes created at the supranational level, such as *Horizon 2020*. Based on the idea of two-way communication and participation in which "researchers and other stakeholders engage and listen to different target groups… including them in shaping research outcomes for mutual benefit…" (SiS.net, 2020), the new dialogue fostered various activities and initiatives that aimed to rebuild public trust in science, scientific institutions, and scientists in general.

Science communication in European higher education and research

Science, research, technology transfer, and innovation have never been so important to society as during the last few decades. In general, globalisation brought the rise of competitiveness and commercialisation, strengthened the importance of the connection between higher education (HE) and research and the global labour market, and put an increased emphasis on the concepts of the knowledge society and the knowledge-based economy. Together with the growing expansion of communication technologies, which enabled the development of new international collaboration models, these developments had a tremendous influence on the world and its societies, and particularly universities, HE and research institutions in all countries, including those in transition. In the last two decades, the mission and purpose of universities, HE and research institutions had to change in societies, and these institutions underwent processes of transformation (with various outcomes and levels of success) in order to be prepared for their new roles, which included new modes of closer cooperation with society.

Many documents, programmes, and initiatives have been introduced in the last two decades at the supranational European level. These documents mainly reflect the political arena and provide a framework for the activities that might be developed in various policy areas at the national and institutional levels. Because of this, various countries and institutions progress in the field at different speeds. Unfortunately, in transition countries, many initiatives are not being implemented, as they are perceived as a "dead letter" or as "cosmetic change" to actual reality. Science communication is only one example of policies that are not implemented. Finally, thinking of science communication only through the lens of the popularisation of science, even though it is one part of the whole concept, makes real progress in this area difficult.

Education, and especially HE, is not fully recognised as a driver of societal development in many transition countries. On the contrary, it is seen primarily as an expenditure and not an investment. A shortfall of funds or economic hardship is frequently presented as a legitimate reason for insufficient public funding and reduced numbers of investors willing to put money into HE and research. Moreover, the number of highly educated people in transition countries is lower, which might have a negative impact on society as a whole. In such an environment, knowledge and research remains mostly in academic milieus, and very often without obvious significance for the general public. Because of this, authorities and policy makers have a certain justification for less investment in these areas and allocating funds to other sectors. Moving forward, comparative data on the percentage of public investment in HE in transition countries and financially more stable countries speaks directly to the strength, potential, and status of research and HE in each individual country (Dagen & Kovačević, 2022). In such circumstances, science communication is rarely viewed as a high priority. As a result, there are fewer initiatives and activities in this area, leading to science communication being generally less developed.

The term mediatisation emerged among scholars during the 1990s (Krotz, 2017), mostly in the analysis of the media's impact on political communication and politics in general (Hjarvard, 2008). It began to develop in parallel with the transformation of the media, which "changed the human communication environment in a fundamental way" (Krotz, 2017, p. 105). During recent decades, mediatisation became "a systematic concept for understanding and theorising the transformation of everyday life, culture and society" (Krotz, 2017, p. 103). Nie et al. (2014, p. 364) define mediatisation as "the process of increasing dependency of society upon media and its logic". Through mediatisation, the media (television, radio, print media, and the Internet with its various platforms) today constitute the central forces in the shaping of public opinion, the dissemination of information, and the construction of social reality. Mediatisation plays an important role in making science more accessible to the general public. While the media enhances the accessibility of scientific knowledge to the general public through the dissemination of information, it also shapes public opinion and perceptions about science and influences cultural norms and values.

Unfavourable economic conditions, unstable governments, and ineffective public policies that are not based on long-term strategies and are often not even implemented, are only some of the elements that make up the national contexts of transition countries. These elements encourage mistrust in institutions in general, and consequently have a negative effect on science and science communication as they result in disinterest in science among the general population. In addition to the fact that science communication is not well understood by stakeholders, the question of responsibility for science communication initiatives also remains unclear. What's more, negative content related to research, research institutions, and researchers themselves in the media and especially on social network platforms – e.g. topics related to research integrity, the appearance of fake diplomas and doctorates, plagiarism, etc. – all serve to devalue research.

Finally, increased mistrust in institutions and authorities has become a problem that extends far beyond researchers and their work. As a consequence, some part of the population finds it very difficult to accept authority in any form, and in particular the authority of scientists whose prominent social role is based on knowledge and research achievements.

Science communication in transition countries: the example of the COVID-19 pandemic

As presented in the previous section of the paper, there are many differences in the areas of HE and research in European countries, especially transition countries. Those differences may be related to the impact of various factors in specific national contexts. Since it is difficult to deal with all of these factors simultaneously, in our analysis we have focused on two that we believe have a decisive impact on the perception of science in the general public, and on the level of public trust in scientific results in various countries: (1) the socio-political environment, and (2) the general public's attitude toward science and education. We took the case of the COVID-19 pandemic, which fortunately has become a less burning issue today, but nevertheless serves as a good example for examining the role of science communication and its impact on society.

Our observations showed the complex interaction of various factors in different countries. A general lack of science communication in transition countries was observed. Less reporting on scientific topics in recent years was observed as well, and this coincides with an increased distrust in science and scientists among the broader public. Furthermore, it was indicated that reduced trust in science might be correlated with citizens' distrust in public institutions and the state in general. In addition, while for many generations vaccination was taken for granted, in particular the vaccination of children, as the COVID-19 crisis came to a head, the issue of vaccination suddenly became extremely present in the public and the media, and particularly on social networks.

Analysis of data on the percentage of people vaccinated against COVID-19 in selected EU member states showed a disparity between western and transition European countries. As presented in Table 1, there are substantial differences among various countries, although the vaccine within the EU was more or less equally available to everyone. Science communication during the COVID-19 crisis was shown to be insufficient in some countries, with accurate information about the virus and its impact not reaching certain parts of the population.

Table 1: Data on the percentage of vaccination against COVID-19 in selected EU member states

Country	Uptake of at least one dose (%)				Uptake of the primary course (%)				Uptake of first booster (%)				Uptake of second booster (%)			
	TP	A18+	A60+	C<18	TP	A18+	A60+	C<18	TP	A18+	A60+	C<18	TP	A18+	A60+	C<18
Finland	82.1%	91.1%	95.8%	43.4%	78.7%	88.8%	95.3%	35.3%	55.2%	67.5%	89.6%	-	16.9%	20.8%	53.5%	-
France	79.7%	92.7%	93.1%	31.7%	77.5%	91.0%	91.0%	27.9%	60.1%	74.7%	83.7%	-	9.5%	12.0%	30.9%	-
Germany	77.9%	93.3%	92.1%	-	78.0%	93.5%	91.2%	-	62.2%	74.5%	86.0%	-	9.7%	11.6%	27.1%	-
Hungary	65.3%	73.7%	83.2%	25.6%	63.2%	71.4%	81.8%	24.4%	39.7%	47.4%	67.3%	-	3.6%	4.3%	10.8%	-
Croatia	57.4%	68.2%	78.6%	5.1%	55.6%	66.2%	77.2%	4.5%	23.2%	28.1%	49.2%	-	0.0%	0.0%	0.0%	-
Romania	42.6%	50.9%	47.0%	7.4%	42.4%	50.7%	46.8%	7.1%	9.2%	11.2%	13.6%	-	0.1%	0.1%	0.3%	-
Bulgaria	30.4%	36.2%	38.9%	2.4%	30.0%	35.7%	38.4%	2.3%	11.7%	14.1%	22.8%	-	1.1%	1.3%	3.1%	-

Source: European Centre for Disease Prevention and Control (retrieved October 6, 2022, from https://www.ecdc.europa.eu/en)

TP = Total population
A18+ = Adults 18+
A60+ = Adults 60+
C<18 = Children below 18

The analytical data collected by the European Centre for Disease Prevention and Control presented in Table 1 indicates substantial differences in the level of vaccination, especially in transition countries, which might correlate with insufficient communication of scientific data related to the pandemic. Furthermore, the data shows there are certain subgroups of citizens within each country that differ from the mainstream in terms of their acceptance and preference for vaccination. The reason for such polarisation might be partially found in insufficient science communication, as people in some milieus were not provided with enough information to understand the risks, prevent the spread of the disease, and make informed decisions about their health and well-being. Our observations recognised that a substantial amount of different, and often contradictory, types of information about the COVID-19 pandemic coming from various sources, including the media, social media posts, and the academic community, as well as official statements and guidance from health organizations and governments, created a level of communication noise which made it difficult for people to separate fact from fiction. This opened up space for misinformation, especially as various conspiracy theories spread rapidly, particularly on social media.

It must be asked who or what contributed to this situation and particularly to the great variety in public perceptions and attitudes. The common assumption that it is easier to influence or even manipulate less educated people seems to have been disproved in the case of the COVID-19 crisis. On the contrary, resistance to vaccination and other attitudes that are connected with doubts in science and scientists often came from the least expected individuals and groups. As a matter of fact, the denial of research- based truths, knowledge, and professional experience even came from prominent individuals in society, which had a significant negative impact on the general population.

The role of the media

The media have exerted enormous changes over institutions (Nie et al., 365). To observe the media's role in the conception of science communication, it is necessary to consider mediatisation's influence on society, which has both positive and negative aspects.

Mediatisation, in general, has expanded the formats and channels through which science communication takes place and allows more interactive and engaged science communication, including direct interaction between scientists and the public. While the media plays a vital role in framing and shaping public perceptions of science and scientific issues, science journalists act as intermediaries between scientists and the public, translating complex scientific concepts into accessible language and making them easier for non-experts to understand. In this sense, science journalists can bridge the gap between the scientific community and the media, and ensure that accurate and reliable information is communicated to the public.

Nevertheless, mediatisation has also brought challenges related to privacy, authenticity, and the quality of public discourse. While it has offered numerous opportunities, it has also introduced challenges and risks to science communication. Oversimplification, sensationalism, and the spread of misinformation or misconceptions about scientific topics are only some of these challenges. In addition, the desire for sensationalism and the pressure to produce attention-grabbing headlines and to gain "clicks" often leads to the misinterpretation or oversimplification of scientific findings in the media, and consequently, among the general public. Dissemination of conflicting narratives in the media, as well as "opening the floor" to science sceptics who either do not understand how science works or are ignorant of the existence of a consensus based on research, has in some cases undermined the careful and rigorous nature of scientific research and its public perception.

The decisions of journalists, editors, and media organisations as to which scientific topics to cover, how to frame them, and which aspects to emphasise influence public understanding, interest, and opinions regarding science-related topics. By focusing on controversial or contradictory scientific research, cherry-picking studies that support particular viewpoints, or amplifying minority opinions, the media can inadvertently sow seeds of distrust among the public and create a false sense of scientific disagreement or debate. In today's digital age, misinformation and disinformation can spread rapidly through social media and online platforms, and the media's coverage of controversial topics, such as climate change or vaccines, often becomes polarised, creating an "us versus them" mentality that further erodes trust. As a consequence, the general public often has little accurate information about research that is being carried out, and is not aware of the role that research has in everyday life. The perception of science and everything around it is often unsatisfactory to both scientists who dedicate their lives to research activities and to the general public.

Without going into all the aspects of specific social contexts, we observed whether the media could have contributed to a better understanding of the COVID-19 pandemic, and how in the framework of science communication the general population might have received relevant, prompt, and accurate information about how to fight the pandemic and its impact on their lives. Finally, we raised the question of whether science communication failed in some countries.

As a first step, it was necessary to look at the role of the media and to observe it both at the time of the pandemic and during the period before the crisis broke out. Our analysis indicated several important differences between countries with long democratic traditions and transition countries. While in the "old democracies" there was the significant presence of scientific topics in the media both during the pandemic and prior to the crisis, less media coverage (if any) in public newspapers was observed in transition countries during both periods. Furthermore, newspapers in countries with long democratic traditions had special sections dealing exclusively with scientific topics even in recent decades during a period when print media was already facing a crisis as a result of the growing influence of television and online platforms (e.g. YouTube channels and social media platforms). In contrast, special sections for science coverage had been reduced or abolished in the public newspapers of transition countries.

Likewise, there are differences in the way that print media reported on scientific topics in the various countries. While in the "old democracies" topics related to science were in most cases covered by journalists who were well-acquainted with a specific area, this was relatively rare in transition countries. Due to the rarity or non-existence of specialised science sections in the print media, topics related to research were not generally covered by journalists specialised in science education reporting. As the publishing of news and stories on other situations tends to attract more readers, editors often did not pay sufficient attention to scientific topics and limited reporting on controversial issues related to HE and research areas. In general, bringing scientific research closer to the readers was a practice more present in public newspapers in countries with long democratic tradition than in transition countries.

Nevertheless, the issue of education is of significant importance, both in the media and the area of science communication. While some universities in western Europe have developed specific multidisciplinary study programmes in science communication in order to educate skilled professionals in this area (for example, the UK, the Netherlands, Italy, Finland, Germany, France), such initiatives are missing in transition countries. What's more, little is done to in transition countries to develop even single study courses dedicated to science communication at universities, which would be a great benefit to further the scientific education of journalists. As a result, journalists in transition countries report much less on scientific topics, and what they do write is usually less affirmative. The tendency to report on scandals and failures of ethical criteria in scientific milieus negatively impacts the amount and quality of media coverage dedicated to science.

Finally, our research extended to the audience and the question of the readership of specific newspapers. As discussed above, changes affecting society have led to a shift in public behaviour, and consequently to the changing expectations of the public. At the same time, transformations in political context, regardless of whether they take have taken place in countries with a long democratic tradition or countries in transition, have tended in recent years to increase the level of populism. As a consequence, clear boundaries between left and right wing are disappearing, and a broad base of the liberally-oriented population, which includes the intellectual elite as well, is not as actively present in public life as it was in the past.

The increase in populism across the global, partially the result of a loss of trust in the existing establishment, and the relative stagnation (or even regression) in improvements of living standards, has created the foundation for the rise of pseudo-science and the spread of distrust in science. Social media platforms have become an uncensored method of communication available to the general population as well as a virtual space for posting various unverified information, comments, and content that may distort scientifically verified facts. This also has the potential to increase polarisation among various groups, and to influence public perceptions and individual attitudes and behaviour.

Because society has proven to be increasingly incapable of dealing with the massive changes affecting it, the role of the media has acquired crucial importance. As the pace of life accelerates (which in turn reduces social reflexivity and critical thinking especially as gaps between the traditional and the digital generation grow) and the speed of reporting becomes an essential element, professional reporting provides the best opportunity for a better understanding between scientists and the public, and for acquainting the public with recent research results. Thus, the presence of scientific topics in the media positively impacts the public's trust in science as it brings a better understanding of research results to the general public, which increases public awareness and trust in scientific truths and in public institutions as well, a phenomenon which was observed during our studies of the COVID-19 pandemic.

Distrust in science – the role of social context and socio-economic factors

In the first part of the paper, we focused on the impact of the media in forming the attitudes of the general public toward science and education. In the next part of the paper, we observed the impact of social context, and especially the socio-political environment in specific countries. In order to better understand the differences between countries, we studied the available data for the periods before and during the COVID-19 pandemic.

In 2018, the global foundation Wellcome Trust generated a report on the results of international surveys conducted by Gallup which measured attitudes about science and health. The report showed that at the time the surveys were taken 18% of people had a "high" level of trust in scientists, 54% had a "medium" level of trust, 14% had "low" trust, and 13% "didn't know". According to this data, a third of the people surveyed in Australia, New Zealand, Northern Europe, and Central Asia had a "high" level of trust in scientists, while only around one in ten had the same attitude in Central and South America (Gallup, 2018, p. 6).

The report also showed that about seven in ten people worldwide felt that science benefitted them, but only around four in ten believed it benefitted most people in their country. In addition, about a third of people in northern and southern Africa, and Central and South America felt excluded from the benefits of science (Gallup, 2018, p. 7). The report showed that people surveyed in Western and Eastern Europe were the most pessimistic about the impact of science and technology on jobs in their countries (7% in Western Europe, 8% in Eastern Europe). In contrast, people from other world regions expressed the belief that science and technology might at least to some extent increase the number of jobs in their local area during the next five years (Gallup, 2018, p. 92).

Among other things, the report also indicated that men are more likely to claim greater science knowledge than women, that young people believe they know more about science than older people, and that almost two-thirds of people worldwide (62%) said they were interested in learning more about science. The report showed that the basic concepts of "science" and "scientists" are not universally understood across all countries, even in high-income nations (Gallup, 2018, p. 6). Finally, internationally, eight in ten people (79%) "somewhat" or "strongly agreed" that vaccines are safe, only 7% "somewhat" or "strongly disagreed". Eleven percent "neither agreed nor disagreed", and 3% said they "don't know". People in France had the highest trust in vaccines. Some 92% of parents worldwide said that their children had received a vaccine to prevent them from getting childhood diseases (Gallup, 2018, p. 7).

A subsequent report by Wellcome, the Wellcome Global Monitor (Gallup, 2020) survey on the way that the COVID-19 pandemic affected people's lives and their views on science, indicated that trust in scientists increased in the period up to 2020, possibly as a result of the COVID-19 crisis. Trust in both science and scientists grew by about 10% in the following three regions in comparison to 2018, where the proportion had been relatively low two years earlier – East Asia (predominantly China), Latin America, and Eastern Europe. In contrast, the level of trust stayed at the same level or declined in the following regions: the Russia, Caucasus, Central Asia, and Sub-Saharan Africa (Gallup, 2020, p. 3). At the time of the pandemic, the survey indicated differences across the world regarding trust in scientists – the highest percentage was found in Australia and New Zealand (62%), while the lowest was indicated in Sub-Saharan Africa (19%) (Gallup, 2020, p. 3). Data for Western Europe indicated that trust in science increased from 50% in 2018 to 59% in 2020 (Gallup, 2020, p. 26).

Furthermore, the number of people who claimed to have "some" knowledge of science grew globally from 39% in 2018 to 48% in 2020, as well as the number of those who claimed to know "not much" or "nothing at all" about science, from 25% to 33%. Roughly 80% of those surveyed claimed that COVID-19 influenced their life (although 45% responded they felt "a lot" of impact), data indicating differences in certain parts of the world with most explanatory comments related to economic issues (losing jobs, stopping working temporarily, receiving less pay, etc.) (Gallup, 2020, p. 26). Finally, only a quarter of the public said that their government valued the opinions and expertise of scientists "a lot". Conversely, nearly three in ten (28%) felt that their government did not place much or any value on the opinions of scientists. As indicated in the report:

In 25 of the 113 countries surveyed, including eight in Eastern Europe and six in Latin America, people were significantly more likely to say their government leaders placed little or no value on scientists' opinions than to say leaders placed 'some' or 'a lot' of value on them. (Gallup, 2020, p. 4).

A more detailed dataset (published only in several selected countries in Europe as noted in the report) indicated that, for example, 44% of respondents in Bulgaria claimed their leaders in the national government value the opinions and expertise of scientists "a lot or some", while 50% said "not much or not at all" (Gallup, 2020, p. 36). Respondents also claimed that governments need to invest more money to prevent and cure diseases either on a national or international level. Unfortunately, the survey did not provide more detailed information on each research question for specific countries, but only gathered data for specific world regions.

The Special Eurobarometer 516 Report on the knowledge and attitudes of European citizens about science and technology (European

Commission, 2021) analysed beliefs in conspiracy theories among the population of thirty-eight European countries. The report indicated that a majority of the overall population in the analysed countries believed that it is not true that viruses are produced in government laboratories to control our freedom (55%) (European Commission, 2021, p. 73). However, data from Romania showed that 53% of the population believed that the proposed claim was true, 31% said it was false, and 16% provided no answer. In Bulgaria, 52% of the population believe that viruses have been produced in government laboratories to control our freedom, 19% think that is not true, and 29% provided no answer. In Croatia, 50% of the population believe the proposed claim, 28% thought it was not true, and 22% provided no answer. The results for Hungary indicated that equal percentages of the population believed or did not believe in the proposed claim (43% for each group), and 14% of the population provided no answer. In contrast, at least seven in ten respondents in six northern countries believed that the claim was false: Netherlands (84%), Denmark (83%), Sweden (75%), Belgium (74%), Ireland (73%), and Germany (70%). In Finland, only 10% of the population replied that the claim was true, while 69% answered that they did not believe it, and 21% provided no answer. In France, 30% of the population believed that viruses have been produced in government laboratories to control our freedom, 54% answered that the claim was false, and 16% did not provide answer (European Commission, 2021, p. 73).

All the presented data indicate a connection between social context and public trust in science and scientists. In addition, it is observed that a range of socio-economic factors deeply impact people's attitudes about science. Because of this, we decided to provide a kind of sociological analysis of statistical data on the following four factors that we believe have a significant impact on the level of trust in science in various national contexts: level of education, economic growth and percentage of GDP, security and economic stability of the country, and presence of corruption.

Table 2: Data on four factors

Country	Population (2021)	Level of tertiary education (%) (2021)		GDP per capita ($) (2021)	Best country rankings (2022)	Corruption Perceptions Index (CPI) (2021)	
		25-34	25-64			Rank	Score
Finland	5,541,696	40.1%	42.3%	53,982.6	#15	1/180	88/100
France	67,499,343	50.3%	40.7%	43,518.5	#9	22/180	71/100
Germany	83,129,285	35.7%	30.9%	50,801.8	#2	10/180	80/100
Hungary	9,709,886	32.9%	29.3%	18,772.7	#48	73/180	43/100
Croatia	3,899,000	35.7%	24.9%	17,398.8	#45	63/180	47/100
Romania	19,115,146	23.3%	18.8%	14,861.9	#54	66/180	45/100
Bulgaria	6,899,125	33.6%	29.6%	26,705.4	#60	78/180	42/100

- Population – The World Bank (retrieved October 9, 2022, from https://data.worldbank.org/indicator/SP.POP.TOTL)
- Level of education – Percentage of Population with Tertiary Degree. Eurostat (retrieved October 9, 2022, from https://ec.europa.eu/eurostat/databrowser/view/EDAT_LFSE_03__custom_2733311/bookmark/table?lang=en&bookmarkId=6fa0f5e0-2450-46be-bdb5-3ba64fcddc42)
- GDP per capita – The World Bank (retrieved October 9, 2022, from https://data.worldbank.org/indicator/NY.GDP.PCAP.CD)
- Best country rankings – The Most Economically Stable Countries. U.S. News (retrieved October 9, 2022, from https://www.usnews.com/news/best-countries/rankings)
- Corruption Perceptions Index – Transparency International (retrieved October 9, 2022, from https://www.transparency.org/en/cpi/2021)

As presented in Table 2, data for 2021 show that selected western European countries (e.g. Finland, Germany, and France) have a higher percentage of GDP per capita than other countries, which is also reflected in the population of citizens with a tertiary-level education, particularly in Finland and France, and to a certain degree, in Germany. Interestingly, this data correlates with the Corruption Perceptions Index (CPI), according to which Finland is considered to be the country with the lowest potential of exposure to corruption, while Germany occupies tenth place, and France twenty-second place. The data in Table 2 also shows the high position of Germany on the Best Country Rankings list (second in the world in 2022), with France and Finland having high positions as well (ninth and fifteenth respectively). Comparison of the data in Table 1 and Table 2 indicates a correlation between the selected socio-economic factors and the level of vaccination against COVID-19 disease in the selected countries, with the total population's uptake of the primary course of vaccination being relatively high (91% in France, 78.7% in Finland, and 78% in Germany).

On the other hand, data for three (see Table 2; Bulgaria, Croatia, Romania) among the four observed transition countries indicate much lower percentages of GDP per capita in comparison with selected long-term EU member countries, a lower proportion of citizens with tertiary-level education, and much higher exposure to corruption. These data could be potentially linked to the duration of EU membership with Croatia joining in 2013, and Bulgaria and Romania in 2007. Hungary, however, was among ten countries that jointly entered into the EU as early as 2004 during the EU's largest enlargement phase. These data correlate with the percentages of vaccination against COVID-19 disease presented in Table 1, especially in the case of Bulgaria where the lowest uptake of the primary vaccination course was observed (only 30% of the total population).

The perspective for improved science communication in transition countries

The presented data on the social contexts and the impact of four selected socio-economic factors in transition countries provide a reflection on the quality of science communication in general and the activities carried out to inform the general public about the results of research and science. In social contexts, it appears that science communication is insufficient and inadequate, and its development has been relatively slow.

Although education and learning about science is important and one of the key factors for the development of society in general, it seems that transition countries persistently lag behind in these areas. This situation should be addressed because the long-term consequences are potentially far-reaching and severe for the development of a society both on the local and global level.

The governments and policy makers in transition countries would need to recognise the important role that scientists and science should play in society. In addition, scientists and science communicators should strive to acquire improved communication skills, and journalists who cover science and scientific topics should be well (or better) prepared for reporting in this area. Following the need for further development of science communication in transition countries, decision makers and university leaders should become more aware of the importance of education in general, and education in social sciences and humanities in particular, with technology directly bringing further development. The need for rapid social progress must include an emphasis on social and humanist education, which should not be detached from scientific fields and other disciplines.

Our analysis indicates that, especially in transition countries, less and less emphasis is being placed on education, in particular educational fields that do not appear to generate quick economic returns. The level of corruption, which often creates the appearance of other ways (and indeed shortcuts) to achieve success and social position, also casts doubt on the relevance of education and reduces faith in experts and professionals dedicated to the creation of new knowledge.

Conclusion – the relevance of science communication

The global COVID-19 pandemic was an extreme situation that shed light on the high level of distrust in science among general populations in Europe, and particularly in transition countries. Further research and analysis could provide additional data and new insights that would help us to better understand a number of contradictions that appeared in the data, but nevertheless the present analysis highlights several relevant issues.

The purpose of science is not only to publish papers and conduct research significant within the field of science itself, but also to make changes in society, and provide information and insights that will help us deal with specific challenges. In this sense, scientific results should be used to help policy makers create progressive public policies that positively affect people's lives. Insufficient investment in HE and science has a negative impact on all parts of society. Countries that perceive it as an expenditure and not an investment tend to lag behind, while societies with an awareness of the importance of science and HE use it as a generator for positive changes and further progress. Education is crucial for the better understanding of scientific topics and provides a foundation for understanding causality, consequences, and connections, which is a precondition for accepting scientific truths and their implementation in everyday life.

Going forward, scientific "content" must be carefully and skilfully presented by scientists and science communicators. Science communication and its continued development is crucial for the process of building trust in science and scientists. In this context, science communication should be perceived as specific know-how and an essential tool in a kit that gathers various models, approaches, and practices for bringing a range of topics to different audiences by using vocabulary and forms that are understandable to the general public. In addition, timing is a key factor as delayed or confused presentation of information can have negative long-term consequences. Furthermore, contradictory, sometimes even controversial, statements from individual members of the scientific community act as potential obstacles to more efficient and successful science communication. Such statements confuse the general public and tend to reduce trust in science and scientific facts. In sum, the public must be continuously exposed to well-presented topics related to science, which will raise the level of confidence in science and the understanding of new scientific results.

Universities in transition countries should invest more in the development of science communication activities and create training programmes for scientists to provide them with the skills needed for the efficient presentation of scientific topics in the media and to a broader public. The establishment of special courses and study programmes in the area of science communication will prove to be beneficial in the long term as they would create a cadre of well-educated and skilled science communication experts and journalists. This would have the consequence of increasing public trust in science in general.

We encountered certain contradictions in our observations. For example, EU countries with a higher percentage of citizens with tertiary-level education (Table 2 – Finland and France; Germany to a lesser extent) and consequently a population that is more exposed to topics related to science and had relatively high vaccination rates, still experienced resistance to vaccination in specific subsets of the population vulnerable to the anti-vax movement. Although this was more evident in transition countries where the anti-vax movement grew during the pandemic, data indicate the existence in all countries of more or less stable parts of the population receptive to pseudo-scientific claims and attitudes. What is most concerning is the phenomenon of anti-vax messages coming from prominent individuals, even those in academic milieus, which led to an increase in the number of people in the general population who did not believe in science and knowledge, and hence also to lower vaccination rates during the COVID-19 pandemic.

Unfortunately, science communication in many countries and milieus does not get enough attention in general. Little, if any, attention is dedicated to science communication activities in transition countries which by definition operate under economic constraints and where educational levels tend to be lower on average than countries that have more favourable economic conditions. Unfortunately, transition countries do not recognise science communication as an important issue, and therefore it is rarely defined as a priority either at the national or institutional level. At the very least, small steps forward are necessary because systematic work on science communication must become a part of the educational reality, from kindergarten and elementary school to higher education.

In general, the data presented in this perspective paper, which was generated by descriptive statistical analysis, indicate that there are subsets of the population that distrust science and scientists. Our observations showed that many different and overlapping factors have an impact on this situation and have caused similar effects in a range of countries. Although mistrust in science is present to some degree in all the countries surveyed, statistical data indicates that a larger population in transition countries is inclined to be sceptical of scientific truths. While the level of tertiary education might be one of the factors influencing scepticism in science in transition countries, dissatisfaction with the economic situation and a general mistrust of institutions and governments also sharpen the thin line between trust and distrust in science.

The COVID-19 pandemic opened a Pandora's box of broad public distrust and misunderstanding of science and scientific knowledge. Because of this, we have become acutely aware of the urgent need to develop and implement activities that might help the general population understand the risks of various diseases and measures that could prevent their spread.

Finally, the analysis of the COVID-19 pandemic is just one illustration or warning of similar effects that could appear in the future in response to a range of situations. It is therefore crucial to find new and effective science communication models and approaches. In an era when society is facing and will face more such challenges in the future, it has become even more important to fully take advantage of the role that science communication could have in the promotion of research output and the identification of suitable solutions for long-term societal problems.

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César Carrillo-Trueba

Between Techno-Science and Post-Truth: The Need for the Creation of the Figure of the Science Critic in the Public Communication of Science

Is scientific culture served by the one-sided glorification of "facts" and presenting objectivity as the absolute norm?

Pierre Thuillier

Introduction

The COVID-19 pandemic that we have just experienced brought to light a number of characteristics about the dominant modes of science communication. More specifically, it has become clear that the flow of information about science is often completely decontextualised, and that it serves commercial, industrial, national, and even geopolitical interests, rather than contributing to an understanding of what is happening, the possibilities for finding solutions on a global scale in a situation like the pandemic, or stopping it completely. What we have instead is a dense fog. The unbridled race to be the first to patent a vaccine led research laboratories to disseminate information without verification, such as the duration of the virus on different surfaces, and this without knowledge of whether it was capable of continuing to infect, and thus triggering a wave of fear. Similarly, one of the vaccines was disqualified because of its side effects, albeit based on data of very low probability, and because of the technology used (not RNA but an "old" one). A great deal of other information was disseminated during this time, much of it out of context, that contributed little to increasing understanding and a lot to increasing fear (Carrillo-Trueba, 2021).

This state of affairs finds its origins in the techno-scientific character of the contemporary economy, which has caused social and environmental changes on a scale that may well be irreversible. Science and technology have been subjected to what Pestre (2003) characterised with great clarity as "the regime of production and validation of knowledge", thus being essentially transformed into inputs for the production of goods, industrial processes, services, and becoming just another commodity used for short-term, profitable, instrumental projects. This impression is exacerbated by the predominance of private investment and the reduction of public investment to the extent that the interests and objectives of companies impose themselves on the orientation of research in universities and other public institutions (Pestre, 2003). In other words, science has been privatised. As Bauer points out, it has gone from being "a public good" to "a private good" (2008, p. 2).

The effects of this new regime of knowledge production and validation on science communication are manifold. The most obvious is its increasing commercialisation, the mediatisation of science communication (Väliverronen, 2021), and its transformation into what Bauer (2008, p. 5) calls "the public relations of science". The primacy of marketing over everything else has led to the introduction of marketing-specific forms of science communication, which regularly appear in public debates (such as the GMO controversy). These marketing-specific approaches include the following: absolute but deliberate decontextualisation in the form of the concealment of methods and sources, which allows the biased interpretation and presentation of information in order to support economic interests; the elaboration of scenarios based on dubious information; the minimisation or maximisation of risks according to the purpose pursued; the use of images, diagrams, graphs, and other visual elements assuming their veracity; the distortion of trends and statistics; the systematic denial and disqualification of researchers who criticise such products, even forcing publications to withdraw their articles and accusing them of fraud and methodological flaws, the intention of the companies being to silence critical voices at any cost. At the same time, companies run promotional campaigns by hiring and paying ad hoc science communicators, subsidising scientific publications, granting advertising to various mass media, financing congresses and other academic events, and even funding fraudulent research to support their views (Bauer, 2008, partially addresses this last point).

This process of commercialisation has had an impact on the ongoing crisis of science communication, in part due to the prevailing persistence in pursuing the deficit model and its vision (Hilgartner, 1990), and also the customary habit of labelling as ignorance any public reaction other than the desired one. It is a case of continuing to try to naturalise risk as something inherent to technological development, without taking into account the fact that the public is becoming less and less aware of the benefits of many technologies, and more and more aware of the risks and fears they generate. Similarly, the promotion of new models of science communication (dialogical, participatory) tends to be a sham, perpetuating the rules of the deficit model, rather than taking into account different audiences and social actors. In short, as Brian Wynne forcefully states, this is nothing less than total myopia in the face of the current situation:

> Scientific institutional actors and the policy officials they advise seem unable to recognise these basic points, as the epistemic culture of instrumentalism and control which defines modern scientific knowledge has been allowed to pervade and latterly to define science-policy institutional culture (2006, p. 220).

The combination of these two phenomena in the current political situation – which itself is characterised by the rise of right-wing populist parties and movements that exploit certain scientific issues such as climate change – has led, in a cascading effect, to a specific mode of scientific communication. The main characteristic of this mode is the intensification of marketing methods in all areas of society, to the extent that the reliability of information does not matter: anything goes as long as it serves a certain purpose. Thus, we have the spread of fake news and the advent of the post-truth era.

The current scenario is strongly polarised: on the one hand, there are the defenders of a neutral and untainted truth, above all social interests (political, economic, etc.), and on the other, there are those who distort, invent, and deny theories and facts for the sake of causes placed above all others (life in the case of abortion; the Great America in the case of global warming). However, as Wynne (2022) points out, this polarisation lends an aura of sanctity to the production and validation of scientific knowledge in the "age of truth" (before the post-truth era). But did truth above suspicion ever really exist before? As mentioned above, it did not. In a sense, the commercialisation of science paved the road to the post-truth era. Either way, it is undeniable that the climate of polarisation has become a boggy marsh. How do we get out of it?

This chapter proposes the need to create the figure of the science critic, which would allow a systematic approach to science in its context and in society – just as the art critic does with art – contextualising scientific results, clarifying research processes, explaining the stakes, and the political, economic, ideological, and other interests at play, and, last but not least, serving as a stepping stone between science communicators and science studies and science communication research where there is still a yawning gap. This may be the only way out of this dichotomy, and indeed out of the crisis that public science communication has been in for some time.

To this end, we will first characterise the dominant way in which science communication is carried out today and, through a typology of the figures of communicators present in the arena, we will describe the most common ways of working in this field. We then go on to show the relevance of the figure of the science critic (with some references to the main features of the art critic, the inspiration for this proposal) and finally to outline the way in which the science critic should proceed. The conclusion highlights the need and urgency of the presence of a science critic in the current situation.

The dominant mode of science communication

After decades of studies (from Kuhn, 1962; Habermas, 1968; Rose & Rose, 1970, to specialised publications, academic programmes, and numerous congresses today), it has been established in the academic world (Social Studies of Science and Technology, Science Communication Studies, etc.) that science is a social activity, and therefore its organisations and even its theories are embedded in the political, economic, ideological, philosophical, and other spheres of society. However, not much of this social embeddedness is reflected in what is read, heard, or seen about science in the media, and in the daily work of science communication. Broadly speaking, this is due to the following reasons:

a) Science news is mostly decontextualised because there is a tendency to isolate the results of its processes – the famous black boxes – and it is framed by a vision where science is intrinsically beneficial and all new knowledge represents progress (Carrillo-Trueba, 1997; Van Gorp & van der Goot, 2012, p. 137).

b) Scientific activity is presented as a provider of material well-being due to the technological development it produces in a disinterested manner, with its own dynamic, driven only by the desire for knowledge (as stated by Popper in 1935), detached from society, and thus generating universal knowledge that can be reproduced anywhere in the world (Pestre, 2006).

c) Science is presented as an activity carried out by morally pure people (Shapin, 2008) who are dedicated to expanding the frontiers of human knowledge, who fight from the heights the obscurantism, ignorance, irrationality, misinformation – or fake news as we call it today (Dawkins, 2006).

d) Knowledge is communicated to the "ignorant public" as it has been described in numerous studies, a public with a knowledge deficit (Miller, 2001), to whom scientists and science communicators communicate in a unidirectional way, using a range of different means and techniques (Burns et al., 2003; Kappel & Holmen, 2019).

e) There is a huge gap separating science communicators from researchers – even researchers of science communication (Bucchi & Trench, 2021). The pandemic we have recently suffered has clearly shown how wide this gap still is (Carrillo-Trueba, 2021).

In short, the present-day vision of science not only has blind spots, but also ends up constructing a very poor image of scientific activity, science – always presented as something homogeneous, without cracks or fissures – and sometimes even of the world itself (Thuillier, 1983, 1988b). Thus, science becomes ungraspable because it is always presented in a fragmented, decontextualised way, without sense, lacking in meaning (Carrillo-Trueba, 1997). The intrinsic heterogeneity or plurality of science is eliminated as are the paradigms that support different positions, metaphors, and their relationship to the larger culture (Keller, 2002). The different ways of doing science and the nuances with which cultures imbue them, that is, the whole complexity of science production and validation, are set aside.

Of course, this situation is neither absolute nor constant. It varies from country to country, and even from region to region. In places where science and technology are more developed, their impact is greater, and there tends to be more reflection and public debate on scientific issues and their implications. (The exception may be countries such as China, where, despite scientific and technological development, there is no debate because of state control of the media). Elsewhere, not only are these debates less common, but they can even be considered sacrilegious if they are critical, as in Mexico ("science in our country is so weak and then they come and criticise it") where the exercise of scientific communication is mainly unidirectional, and the criticism of science, the questioning of its orientation, is considered to be a "luxury" of countries where it has already been established (Kreimer, 2015).

Many of these debates are part of what has become known as "scientific controversies" and, as is well known, they go well beyond the strictly scientific framework (Brossard, 2009).

However, similar to the situation we live in today (between truth and post-truth), the polarisation that emerges from these debates overshadows many important aspects of the understanding of the matter at hand, simply for the sake of defending one's own positions and winning the debate or a lawsuit if it comes to that. And these debates are frequently distorted by the Manichean way in which they are presented: one side is right and the other is wrong, one side defends pure science and the other mere ideology, one side is driven by corporate interests and the other does science for the common good. In the process, both sides gain allies and form seemingly well-defined factions (Latour, 1987; Brossard, 2009). The final outcome is disconcerting, as the winner becomes either the champion of SCIENCE or yet another villain who stood in the way of an undeniable truth.

Furthermore, a deeper look would reveal that opposite positions arise from the same situation, that is, there is symmetry in the causes that produce both effects (Bloor, 1976). The case of James Watson and his racist remarks in 2007 is a case in point. There was little reflection on them and the Nobel Laureate was simply declared senile. Closer analysis, however, revealed that Watson had made similar comments on other occasions, namely that biological determinism has many common features with molecular biology, and that genetics have been given a primacy in the understanding of human nature. In other words, it wasn't merely a detour from the right path (Carrillo-Trueba, 2009). The same lack of symmetry can be found in debates about scientific fraud. Whenever a case occurs, it is quickly categorised as an anomaly, but as Broad and Wade have argued, it is a more common practice than usually thought: "The roots of fraud lie in the barrel, not in the bad apples that occasionally come to public attention" (1982, p. 108). Even when such controversies erupt, it is still not common practice to integrate discussions and reflections on science as a social phenomenon into the daily practice of science communication.

Finally, in light of what has been outlined above, we can state that what several authors have called the crisis of science communication lies largely in the dominant mode of science communication, which some authors have even described as a failure (Wynne, 1992b; Bauer, 2009; Miller, 2001).

Figures in the field of science communication

As is widely recognised, science communication is a field that is not fully defined (cf. for example, Bucchi & Trench, 2021, p. 3) and is delimited by various criteria. It is defined either by its mission (PAS, PUS, SL, SC, according to the terms defined by Burns et al. (2003), called paradigms by Bauer et al., (2007)), by the objectives it pursues (nine according to Thomas & Durant (1987), eight according to Kappel & Holmen (2019)), by the modes of communication used (unidirectional or dialogic, called paradigms by Kappel & Holmen (2019)), or by the models it follows (Deficit, Contextual, Lay Expertise, Public Engagement, from the perspective of Brossard & Lewenstein (2010)). These definitions overlap, moreover, by the innumerable means and activities, techniques and tools used to reach the equally numerous audiences: science centres and museums, television, film, radio, print, theatre, science clubs, the web, and a long etcetera (Burns et al., 2003). In practice in this field, the combination of such elements generates a complex topography. In other words, in everyday work, the typologies overlap, the boundaries between paradigms, objectives and models become blurred, and the means and activities multiply.

On the basis of the above and in order to characterise what the figure of the science critic should be, we will first present an outline of the typology (in the process of elaboration) of the figures that perform in the field of science communication. This typology was elaborated based on the concept of the "frame", taken from the cognitive sciences, which is now widely integrated in the study of communication (Lakoff, 2014; Van Gorp, 2007; Scheufele, 1999). The concept of frame refers to the ideas, values, and intentions that guide and delimit the work of science communication that an individual carries out. Throughout history, it can be seen that the appearance of these figures (and these modes of communicating science) takes place in specific periods, and in a certain way they correspond to the periods that Pestre (2003) defined in his characterisation of "the regimes of knowledge production".

It should be noted that these figures are ideal types, designed for heuristic purposes (good for thinking, as is said in anthropology) rather than as finished classifications of the universe that science communicators currently comprise. In all cases, however, it is possible to find science communicators who correspond to these types and with whom one usually interacts, discusses, and collaborates on various projects.[1] The value of this typology is that it highlights contrasting positions, perspectives, intentions, and interests, and thus the characteristics that a science critic should have. And it could well form the foundation for the development of a classification of science communicators, or of the modes of communicating science through empirical research.

For the time being, ten are listed here (with a touch of humour to honour the memory of the recently departed Bruno Latour).[2]

The Illuminist

The Illuminist[3] is a figure who is convinced that the progress of humanity can only be achieved by spreading scientific knowledge, its results, its truth, and that science is a beacon that will eradicate the darkness that still haunts mankind (superstition, beliefs of all kinds, including religious ones, traditions that hinder progress). This is why, like Don Quixote, she constantly fights against everything that is not scientifically proven, against pseudo-sciences (such as homeopathy), which she considers irrational, anachronistic, and destined to disappear. For the Illuminist, everything that comes from science is inherently good.

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1 Steven Yearley (2021) discusses the figure of the environmentalist as science communicator in the context of the current climate change debate in a similar way to what is proposed here. Such a figure would play the part of "the activist" in the typology presented here.

2 Humour does not detract from the respect I have for the community of science communicators to which I belong. These are my colleagues, with whom I collaborate, share, discuss, and even debate vigorously, and who send articles to the journal of public science communication of which I have been the editor for more than three decades. Not without some embarrassment – for an editor keeps secrets like a doctor – I confess that this typology takes my work as an important reference. The journal called *Ciencias* is published by the Faculty of Science of the National Autonomous University of Mexico (print and digital versions are available: https://www.revistacienciasunam.com/es/.)

3 In these descriptions, the feminine gender pronoun is used in some paragraphs and the masculine in others to avoid the duplication of she/he; it does not correspond to a specific gender for a particular figure, there is both in all categories.

The Scientist

The Scientist is attached to the great syntheses of thought, which makes him a typical figure of the nineteenth century. With the development of science, many philosophical systems based on scientific knowledge appeared (materialism, monism, positivism, etc.) that influenced the thinking of the time. The Scientist is a prolific writer, usually covering long periods and vast areas, easily the whole of mankind. He has perpetuated himself by the weight he has acquired in the constitution of the popular image of human history (from Ernst Haeckel to Jared Diamond), and of what is called "human nature" (from Herbert Spencer to Richard Dawkins). Usually, in his works, the social and economic system is naturalised by means of biological and social determinism. He elevates scientific knowledge, its way of knowing, as the only and indisputable basis for understanding the world, its past and future, its direction and transformation.

The Educator

The Educator promotes the scientific method, which makes science unique and superior to all other forms of knowledge and has been established as the main characteristic of science, as a fundamental element of education. She is a tireless promoter of experimentation, whether in physics, chemistry, or biology, or even applied to agronomy and electric power generation. She is convinced that this is the only way to establish scientific thinking, which is indispensable for solving all social problems, from food to climate change.

The Civiliser

The Civiliser is an enthusiastic promoter of the material progress of society based on the technological advances generated by science, both in the city and in the countryside, in developed and underdeveloped countries – where, he asserts, it is even more necessary for civilisation and development to become a reality. He is convinced that technology, hand in hand with science, is the engine that drives the world.

The Functionary

The involvement of the state in the management of scientific and technological development, and in the promotion of research itself, has given rise to new types of science communicators, including the figure of the Functionary who is responsible for the dissemination of information by government institutions and their agencies (including universities and research centres), as well as by international bodies (FAO, UN, etc.). Her theme is the solution to the problems affecting the various sectors of society, regions, continents, or the entire planet, for which research and technological development are crucial – (is there any other way to solve them? indigenous peoples are invited to the forums to give a little colour…) – on the basis of which she draws up local or planetary plans in international coordination.

The Marketer

More associated with the private sector, the figure of the Marketer appears with increasing regularity in controversies concerning products and technologies that in some way affect one or more social sectors. He is the defender of knowledge linked to capital, alienated by patents, of corporate investment in technological development aimed, he claims, at solving social problems (GMOs for food production, energy supply by wind farms), and crucially, of the right to profit from it. The neutrality of science and the benefits of technology are his banners, private contributions in the face of public cuts are his shield, and marketing is his sword.

The Entertainer

Convinced that science is a good thing in itself, and that the most important thing is to bring its marvellous achievements to as many people as possible, the character of the Entertainer devotes herself entirely to using her enthusiasm to spread the taste for science and science for its own sake. Visits to science centres and museums, fairs, workshops, theatrical performances, the cinema: all is used to accomplish this. Entertainment is a means of absorbing science, far from any uncomfortable social issues.

The Plotter

Perhaps because of the secrecy of laboratory work and its imaginary resemblance to alchemists and sorcerers, there has always been the idea that scientists are forging something inside that we do not know about outside. With the involvement of the state in the creation of large projects such as the Manhattan Project this fear has only grown. Today the figure of the Plotter has become very present and active on social networks and in the media, as we saw during the COVID-19 pandemic and with the issue of climate change. He takes scientific information, decontextualises it, reinterprets it, distorts it for his own purposes, and presents it as the truth, arguing that what is officially circulating is not accurate because it is manipulated: a conspiracy in short. He is a science communicator who uses everything to forward values and interests that he puts above all else, elaborating complex frames, as Lakoff (2014) has pointed out on many occasions and bordering on what Bauer calls "bullshitting" (2008, p. 6).

The New Age Figure

The disillusionment caused by the use of the Hiroshima bomb, the Vietnam War, the growing reductionism of scientific theories, the increasing instrumentalisation of technology, and the dehumanisation that all of this implies, have given rise to a way of approaching science that is embodied in the New Age Figure, characterised by the search for holism, theories with a spiritual aspect (quantum mechanics, deep ecology), alternative technologies, natural medicine, certain proposals of neuroscience, in short in any scientific production that approaches an Eastern or ancestral philosophy and helps to preserve this forgotten part of the human being. (A well-known example is Fritjof Capra, 1975.)

The Activist

The Activist is a central figure in debates on issues relating to science and technology (GMOs, nuclear energy, labelling of industrially produced foods, pollution, etc.). The Activist's scope for action tends to be limited, as she is completely committed to a specific issue and usually for a specific period of time (e.g. the passing of a law), although there are collectives such as Greenpeace that are constantly present on a range of different issues. She mobilises a wealth of scientific information and forges alliances with researchers and groups involved in or affected by the issues in question, and therefore has considerable influence on the development of those issues and on public opinion. Her peculiarity lies in the fact that she is perhaps the only figure that always addresses the political, economic, and social dimensions of scientific and technological activity, albeit in a somewhat Manichean way.

The science critic

Like the critic of art, literature, film, or theatre, the main task of the science critic is to contextualise. In other words, the science critic should analyse the social and historical situation of scientific knowledge production, the relationships between theories, schools of thought, philosophical and political currents, the different styles of research (even of a national character), the use of metaphors, cultural influences, forms of scientific imagination, and much more. This is because science is inseparable from culture and shares many characteristics with the ways culture and art represents the world (Godin & Gingras, 2000; Goodman, 1978; Van Gorp, 2007). The analysis of the science critic should consist of four steps: 1) deconstruction; 2) addressing science in society (opening up relevant issues, generating dialogue, and reflection); 3) giving meaning to the production and validation of knowledge, and; 4) contributing to the formation of a scientific culture.

Given the dominant vision in society of what science is, the production and validation of scientific knowledge, and technological development which is generally reproduced in science communication (Hilgartner, 1990), the first task of the science critic should be its deconstruction. That is to move from SCIENCE to the sciences, which means their social insertion, the way they participate in the creation of the social (Pestre, 2003; Latour, 2005), as well as dismantling its image of neutrality and immanence – the image of the researcher as a saint and laboratory martyr – and its assumed Popperian dynamics and absolute objectivity. In a pluricultural world and in democratic societies, it is also necessary to take into account the claim of science's universal character as the only valid form of knowledge in contrast to other cultures, and the homogeneity with which it is usually presented.

To many science communicators, this may seem like a radical, relativistic position that ultimately diminishes science and its mission. However, it is based on decades of very serious and rigorous research, derived from the STS (Science, Technology, and Society) perspective, which is the source of many concepts, tools, and forms of analysis, and offers ways of entering this universe in a subtle and detailed way in order to understand it. The daily work of science is therefore fundamental to science communication as it allows us to recover the complexity that characterises scientific activity in society and to humanise the scientist, perceiving him as just another citizen, subject to prejudices and ideas that inevitably influence his work, albeit not necessarily in a negative way. This could be a good starting point for addressing "science in society".

Given that form and content are closely linked in communication, science critics should lean toward the dialogic mode, generating topics of common social interest, encouraging reflection on them, and opening up conversation around them (following the proposals of Bauer, 2008, and Bucchi & Trench, 2021). In order to do this, they must be committed to providing certain information, concepts, theories, processes, and may sometimes resorts to the diffusionist mode, but always in relation to context, the plurality of elements, and reflection on different positions. The scheme proposed by Bucchi and Trench (2021, p. 8) can be seen as an account of the continuum that exists between one mode and the other (the diffusionist at one end and the dialogic in the middle), taking into account, at the other end, the participatory mode of communities and individuals whereby they intervene in the issues that concern them, but also in the design of research policies – something that is very necessary today and an activity into which the science critic can also venture – and, of course, the policies of public science communication.

By privileging the dialogical mode, we take up the critique of the way in which certain governmental and private entities have used it to mitigate the loss of trust in science and technology, as well as in their institutions (Wynne, 2006; Gregory, 2016; Burns et al., 2003; Miller, 2001; Bucchi & Trench, 2021).

Even if we were to accept the definition proposed by Bucchi & Trench that "science communication is the social conversation around science" (2021, p. 6), once the most appropriate mode of communication for the work of the science critic has been defined, the question that inevitably follows is the content and the way the communication is put together in order to make sense. This is the most laborious part of our daily work.

Perhaps our priority should be to avoid the decontextualisation prevalent in the way new research results and technologies are presented in most science communication. As the mathematician Rene Thom put it: “What limits what is true is not what is false, but what is insignificant” (1991, p. 132), i.e. the proliferation of news that has no meaning for the public and is therefore insignificant, and the excess of information characteristic of this era that ends up trivialising research work. Contextualisation does not mean simply adopting the so-called contextual model (Brossard & Lewenstein, 2010), but rather recovering the image of the world that the sciences produce in a fragmented way, due to the prevailing hyper-specialisation in the production of knowledge (as in the industrial chain stemming from Taylorism (Carrillo-Trueba, 1997). It is necessary to integrate the contributions of each discipline to the subject in question: the different views, the way they are spun to avoid reductionism and recover levels of organisation, non-linear processes, the emergence of properties, using these and other concepts from the philosophy of science that are heuristic in the elaboration of an integrating vision.

Contextualising science also means bringing together traditionally distant areas, such as the social sciences and the humanities, with the so-called hard sciences. Given that scientific issues of social relevance are hybrids (Latour, 1999) – i.e. combining economic, political, historical, social, ethical, philosophical, and even ontological aspects – it is necessary to integrate the contributions of these disciplines in order to understand science in society, to make more sense of the different elements that make up the issue being addressed, to contextualise it, and make it as meaningful as possible for the target audience. In short, the work of the science critic is formative rather than informative; it is heuristic because knowledge is generated in relation with the public.

In this sense, the context of the public is fundamental. This context includes the public’s perception of scientific knowledge and, above all, of technological innovations, their social impact, their risks, what they imply in terms of the culture in which they function, the values they might presuposse (Van Gorp, 2007; Scheufele, 1999), and how they are perceived in the world. For example, the cultivation of genetically modified maize in Mexico is seen not only as a health risk but also as a threat to a food that has enormous cultural, symbolic, and even cosmological value in certain regions. It is also important to realise how much science has tended to target those already in the know, and now to extend communication to audiences that are not, which requires knowledge of their context and well-defined strategies (Nisbet & Scheufele, 2009, p. 1776).

The cultural context is even more important in pluricultural countries that are made up cultures completely different from western culture, that maintain their own ways of living, thinking and knowing, including the languages that are the reservoir for all of the above. Here the dialogue is of an intercultural nature and implies being located in the ontological sphere, since what exists, what is possible, and what is causal is based on different premises that are as valid as others in their respective contexts.[4] Of course, even in developed countries that do not consider themselves to be pluricultural, it is possible to find populations that, by virtue of their way of life, maintain characteristics different from the dominant values, including their own forms of knowledge. This was true in the well-known case of the sheep farmers from the Lake District of Cumbria in the north of England (Wynne, 1992b).

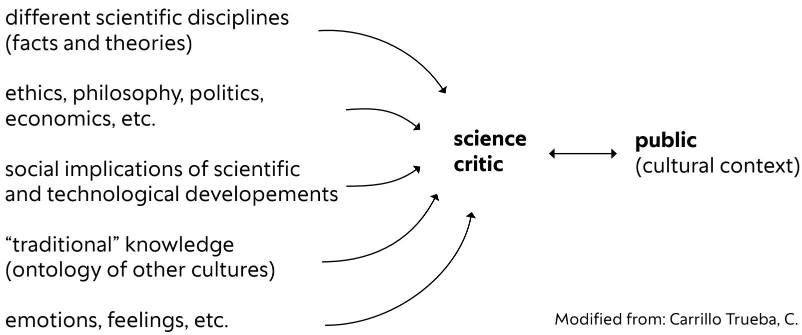
Finally, there is an aspect that has long been marginalised by the prevailing rationalism in science and its communication, and which is only now being taken into account thanks to neuroscientists such as Damasio: namely, emotions. It is necessary to mobilise emotions both in the work of deconstruction and in that of giving meaning, both in the way of establishing dialogue and gathering relevant information, always using the possibilities offered by the medium used. It is well-known that without emotion there is no knowledge (Damasio, 1994).

Integrating all these elements into the work of the science critic (Figure 1) means making frames explicit, dismantling them, and constructing new ones, because frames play such a fundamental role in communication (Scheufele, 1999; Van Gorp, 2007; Nisbet & Scheufele, 2009). However, this requires time and hard work, since the dismantling of the dominant frames means their replacement by new ones, and such adoption is never immediate because it requires a deep change (Lakoff, 2014). As explained by Gregory Bateson (1972), the frame is not exter-

4 This concept was developed in my book *Pluriverso: un ensayo sobre el conocimiento indígena contemporáneo* (2006).

nal, like that of a photograph, but it is imbricated with what it delimits. This means that the frame in some way provides the science being communicated with attributes. It gives the science meaning because it is constituted by ideas and values as well of ways of seeing and relating to the world that are shared by a social sector. (Van Gorp and van der Goot wrote an interesting work on this subject, 2012.)

The science critic:
the work of integration



Modified from: Carrillo Trueba, C. 1997.

It follows from this discussion that the practice of science criticism presupposes certain qualities, also identified by various researchers. One is "reflexivity" (Bloor, 1976; Bourdieu, 2001, 2003), which means that science critics must begin by being critical of their own work, positions, ethics, and values, and the knowledge they mobilise. This is a central aspect of the science critics' work since the relationship of trust they seek to establish with the audience depends on this reflexivity. Science critics must also avoid pontificating, making speeches and general statements that are empty of content (Gregory, 2016). This implies a degree of scepticism, which is crucial in the communication of science, especially taking into account the claims of science often made under the banner of absolute truth (Bauer, 2008, p. 13). However, as Wynne points out, it demands that ethical and other dilemmas must not be avoided, and indeed making clear the values that drive a debate in order to foster trust (2006, p. 220). In other words, the limits of science and technology must be openly admitted without undermining them, but as an inherent quality in the way the hybrid nature of the issues at stake are constituted.

Of course, science critics may want to take a stand on a particular issue, but then it must be done openly and clearly. Before doing so, however, they must problematise, give voice to the different positions and actors, weigh up the arguments at stake, and the different perceptions and frames as the aim is to provide the necessary elements for understanding and taking a position on the specific issue. By taking a position in this way, science critics participate in the formation of opinion by showing the plurality of perspectives and thus also contribute to the democracy of a society.

As mentioned above, science critics should not only focus on the issues of the moment, but also delve into the intricacies of the production of knowledge, that is, uncover the black boxes behind the processes, the paths followed, life in the laboratory, styles of research, the scientific imagination, aesthetics, language, and metaphors used: in other words, the creation of science in its crucible. This is a vast field that has been fruitfully cultivated by historians of science and that is attracting renewed interest from the perspective described in this section. There are many cases that illustrate and allow a better understanding of science in society, but they must be presented from a point of view that enters an almost intimate sphere. Such perspectives are currently very rare in science communication.

In the long term, the work of science critics should contribute to the formation of a scientific culture in society. This is understood here not as a synonym of Scientific Literacy or Public Understanding of Science (Burns et al., 2003), but from a more anthropological perspective, that is, as a collective dimension embedded in the dominant culture of a society, with its particularities in the different collectives and communities that coexist within it. It should also be understood from an individual perspective, which takes into account the inevitable differences between individuals, often only of degree, but also quantitative and qualitative differences when they are expressed by groups with distinct cultural traits that distinguish them from other groups.

Since each society is endowed with institutions that contribute in different ways to the maintenance of its culture, the different types of science communicators who operate within these institutions play a crucial role in shaping the scientific culture of a society. The way in which collectives relate to scientific knowledge and technological innovation depends on the cultural context. The fact that in India there are Ayurvedic (traditional medicine) hospitals created by the state is not surprising, since both society and doctors share the same cultural background regarding the causes of disease and the way to cure them. It is interesting how science is inserted into this context, into the relationship between patients and doctors, and how clinical research is carried out in this context, and articulated by and in other scientific institutions.

The three models presented by Godin and Gringras (2000) to explain the relationship between science and technology and culture are suggestive. Namely, they are not two separate entities, nor does one inform the other. In fact, science and technology are immersed in a specific culture and therefore acquire the attributes, modes, and characteristics of that culture. They are also embedded in and intertwined with other forms of knowledge.

It is in this social and cultural reality that science critics will participate in the formation and transformation of the scientific and technological culture of collectives, individuals, and society as a whole. A critique of the rules that guide the work of other science communicators, of the institutions and actors they represent, and the alliance among them, the complementarity that may exist in certain situations, the dialogue that science critics maintain: all of this shapes the actions and communication of science in society.[5]

5 It should be noted that this proposal is inspired by the work of several science communicators who share some of the characteristics described here: Stephen Jay Gould, Evelyn Fox Keller, Steven Rose, James Gleick, Richard Lewontin, Christophe Bonneuil and, in particular, Pierre Thuillier, from whom I took the idea of creating the figure of the science critic which, although he did not develop – life did not give him the time – showed the way forward with his ceaseless and passionate work.

Conclusion

Studies on the public communication of science show that this is still a field in the process of being defined and constructed, and thus still immersed in debates and ongoing reflections. To the contrary, those engaged in the practice of science communication tend to maintain fixed modes, purposes, ideas and styles, to the point that they can be grouped according to the rules they follow and what guides their practice (the ten figures outlined here), without departing too much, as a whole, from what has been called the "dominant mode" of doing science communication (Hilgartner, 1990). However, the current situation in the production, validation, and communication of scientific knowledge has changed so dramatically that an increasing number of communication scholars are pointing to the need for substantial changes in the way we work in this field.

Indeed, as mentioned above, the highly techno-scientific character of the economy in recent decades has led to the increasing commercialisation of scientific activity. The objective of obtaining patents in research projects is an example of this. The existence of university theses the content of which cannot be published because they have been financed by companies – "under embargo" as it is termed – and whose defence is not open to the public, is proof of the level of privatisation that scientific production has reached in the public sphere (Pestre, 2003, p. 108). This has had unfortunate consequences on areas and disciplines that are focused on understanding certain phenomena, theoretical and conceptual development, and even in the mythical curiosity of the scientist. As Bauer (2008) points out, the very ethos of the scientist has changed from the search for truth that characterises them in the social imaginary, to the search for patents, the creation of companies and marketing; from the university laboratory to the start-up, from the distracted-scientist-genius to the businessman-watching-the-stock-market.

This new regime of knowledge production and validation on science communication has many effects. The most obvious is its increasing commercialisation of science communication, its transformation into promotion rather than communication for understanding the world and shaping a scientific culture in society. Certainly, as Väliverronen

(2021) explains, this process is immersed in the growing mediatisation of the whole society (greater in certain parts of the planet and certain social sectors), driven by changes in the media due to the penetration of social networks, and finally by the hand of "market forces" which now extends to all of society (Väliverronen, 2021, p. 133). The result is first the complete mediatisation of politics – developed and exploited by right-wing movements – and then of all other social spheres from education and health to war, climate change, and science.

It is difficult to discern whether the main cause is social networks, right-wing political movements, the strength of large corporations, or some other factor. As Väliverronen (2021) explains, the empire of marketing in the production and communication of science, even in the training of science communicators at universities, is the result of the combination of all these factors.

What is clear is that this mediatisation has prompted an accelerated urge in the field of science communication to master and make the most of social media. This in turn has generated numerous studies on these phenomena. Once again, the lack of dialogue between science communicators and academics is evident here, as several well-known researchers in this field have been sounding the alarm, and some, such as Miller, for quite a long time:

> If we are entering a new age for public understanding of science, it is important that citizens get used to scientists arguing about controversial facts, theories, and issues. Only in this way will more people get a clearer idea of the potential and limitations of the new wonders science is proclaiming (2001, p. 119).

And more recently, in relation to the forms of communication under discussion (unilateral, dialogical, and participatory), Gregory points in the same direction:

> We should be careful about concentrating intellectual and other resources exclusively in apparently socially-orientated dialogues about new technologies, given that they neglect the content of science, serve economic interests rather than responding to public concerns, and let scientists off the hook of their social responsibilities. New technologies are exciting and can be useful, but they are

> rarely necessary or urgent – except for the investors, who benefit from the work we all do to socialise their ambitions (2016).

Clearly, we cannot proceed without questioning the modes that have characterised science communication over time and which are embodied in certain figures who become obligatory interlocutors in the design of a new way of conceiving of this activity. Thus, the new figure, the science critic, will have to engage in dialogue and debate with them, revealing to them the contributions of science communication to society. It will be a regular and ongoing task. The treatment of science in society must be constant and not limited to moments of controversy and heightened public debate. As Bauer emphasises:

> Public vigilance and debate are urgently required. How will the public sustain a critical conversation when scientific information is leaning heavily towards advertising, strategic public relations, and propaganda in the service of private interests? Where can we find the vestiges of a sceptical public to sustain the vigilance needed to the call the bluff on fraud and high-tech snake oil? The source of quackery is no longer outside science: it is high-octane itself (2008, pp. 8–9).

The creation of the figure of the science critic is fundamental in overcoming this situation, in constructing a social and contextualised perspective of the production and validation of scientific knowledge and of the communication of science itself by bringing the reflections and debates from the field of research closer to practice through dialogue with the other figures with whom we coexist in this field. It is perhaps the only way out of the swamp between techno-science and post-truth where we find ourselves, the necessary lever to get out and move in another direction, towards the construction of a true scientific culture. As Bauer concludes, this is fundamental for a democratic society: "The community of science communicators might recognise here its new mission: to empower public opinion to recognise the exaggerated claims of private knowledge marketing" (2008, p. 14).

The dilemma between defending science above society (or possessing a truth of inviolable purity) and embracing the post-truth era is a false dilemma (Wynne, 2022). In fact, it is not even a new dilemma. It happened to Stephen Jay Gould more than twenty years ago, when his criticism of the prevailing neo-Darwinism in evolutionary theory was taken up by creationists who fought to ban its teaching in American educational systems (Gould, 1981). However, it has now taken on larger dimensions as was seen in the case of Bruno Latour's criticism of certain aspects of climate change theories used by climate change deniers, and also during the COVID-19 pandemic. It is a dilemma that is not only false, but perverse, because it places us in a situation that is so uncomfortable it can be paralysing: by criticising the current dominant regime of knowledge production, are we providing ammunition to the negationists? Are we ourselves fuelling the post-truth era? When Bauer (2008) states that a more sceptical public is needed to counter the growing commercialisation of science, is he empowering the climate sceptics who use conspiratorial arguments and fake news? The answer is an emphatic no.

The following question raised by Pierre Thuillier several decades ago is still relevant today: "Is scientific culture served by the one-sided glorification of 'facts' and the presentation of objectivity as an absolute norm?" The answer is even more evident today: not only is scientific culture not glorified, it is affected and even diminished, as we have seen in several of the current debates. By not addressing science in society, we have left the myriad aspects of knowledge production and validation in the hands of others (private knowledge marketing and post-truth standard bearers). Regaining this ground is an urgent task. The proposal to create the figure of the science critic to communicate science to society has this as its primary aim.

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Noemi Crescentini

Citizen Science: A Reflection on New Ways to Communicate Science

Theoretical framework: science communication

The relationship between science, technology, and society is become both increasingly interlinked and relevant. Communication is thus becoming even more essential for the functioning of contemporary democracies (Jasanoff, 2017). The practice of communicating and disseminating science knowledge can be defined as the social activity that effectively makes science a public good (Cerroni & Simonella, 2014). Science communication aims to reach various types of non-experts (Nowotny, 1981) and also to define the relationship between scientists, researchers, and citizens (Bucchi & Trench, 2014).

A part of science communication outreach takes place in written form in books and newspapers. Another part is oral communication that takes place during science festivals, lectures, and seminars, and on radio and television. A third part is web-based communication, which has become an inevitable element in contemporary science communication. Indeed, the Internet, during the period of its own evolution, has become the media environment that has most revolutionised science communication (Crescentini & Padricelli, 2023). As a result of the "socially-distributed" redefinition of the validity, trustworthiness, and authoritativeness of scientific knowledge, today's digital technologies have lowered the boundary between science and pseudoscience. At the same time, digital technologies provide increased opportunities for representatives of science to experiment with new forms of disseminating science knowledge (Scamuzzi & Tipaldo, 2015). Scientific communication skills not only benefit scientists but also help them to interact with the public and contribute to broader societal goals (Akin et al., 2021). In recent years, we have witnessed the mobilisation of scientists and research institutions intervening in public debate through information, communication, and citizen involvement initiatives (Saracino, 2020). This is in part because "the public space has been transformed by focusing on citizens as repositories of the structures and processes of democracy as control of power, delegation of the popular will, public discussion, and public opinion" (Mazzoleni, 2004, p. 17). Here we are thinking, for example, of the definition of the communication interaction scenario within the policy context, which can be decisive especially when the media not only question science policies but also the relationship between expertise and policy-making (Bucchi, 2010).

The system of scientific process attributes a strong developmental component to the communication of science, which is composed of the ways in which scientists convey the results of their work to others (Greco & Silvestrini, 2009): hence, the necessity of the daily work of scientists to be fully integrated into the so-called knowledge society (Cerroni & Simonella, 2014). On one hand, it is necessary for scientists to communicate with scientists belonging to different scientific communities, and, on the other hand, with institutions, companies, politicians, civil society, opinion leaders, technicians, and citizens. Beyond different levels of analysis of communicative phenomena and the coherent models that delineate the relationship between science, scientists, and various audiences (Jasanoff, 1997), studies of scientific communication generally agree that "the role of the mediator is a central variable in the regulation of meaning-making processes, capable of orienting exchanges between the sender and the receiver towards results that are by no means obvious, even with equal message content" (Scamuzzi & Tipaldo, 2015, p. 68). The communication of science should therefore be seen as a vital part of the public sphere, with its purpose being not only to entertain but also to equip and empower citizens (Davies, 2022). Currently, "a scientist is socially valued if he or she manages to reduce the distance that is often created between subjects surrounded by an aura of knowledge and ordinary mortals. In this perspective, we grasp the need for a close relationship between science and society, between experts and the public in a process of engagement" (Pellegrini, 2018, p. 33).

For there to be citizen participation on ethically sensitive issues, we must consider the cultural and social attributes of those who decide to act and interact with experts. This concept, amplified in the model on which this paper focuses, considers forms of interaction in the category of CS that have recently been gaining relevance (Horst et al., 2017).

Citizen science: definitions and reflections

Public participation in the field of science and technology is primarily driven by citizen empowerment and democratic engagement (Bucchi, 2006), but also by the need to address technical-scientific controversies. Today citizens are increasingly interested and open to understanding and intervening in matters related to science and technology that directly concern them. Because of this, many scholars do not limit their work to the dissemination of knowledge through the media, but also make use of new approaches such as CS which represents the contemporary frontier between science and society.

The term CS refers to projects that involve both professional scientists and amateurs in the process of collecting, evaluating, and/or calculating various scientific data (Kostadinova, 2011). CS can therefore be defined as "the active participation of the public in scientific research." It involves voluntary collaboration aimed at the systematic collection and analysis of data, and leads to the development of knowledge in various fields of study that are part of the human-social, technological, and natural domains.

CS projects are often top-down initiatives directed by researchers in which professional scientists enlist the help of volunteers to gather or analyse data. When the term CS entered the lexicon in the early 1990s, it emerged from two very different sources. First, researchers at the Cornell Lab of Ornithology in New York used the term to describe a process in which volunteers passionate about birdwatching shared observations and data about birds with biologists conducting scientific research. The activities of these citizen-scientists were generally confined to data collection for projects conceived by professional scientists. Second, the same term was used as the title of a 1994 book written by sociologist Alan Irwin in the United Kingdom. Irwin's interpretation of CS was that expert researchers could attend to the needs and concerns of citizens by drawing upon the knowledge possessed or developed by the citizens themselves (Irwin, 1994). This interpretation invokes a scientific paradigm in which research conducted by professional scientists is deeply connected to the needs and activities of public communities. After all, science can be considered "the heir to an uninterrupted lineage of organic forms of knowledge acquisition, reaching back in time to the origin of life on earth" (Ziman, 2002, p. 20). From the 1990s to the present, CS projects have aimed not only to share data and scientific information, but also to raise awareness and involve citizens in current issues such as pollution or the effects of climate change. According to the scholar Muki Haklay (2013), the term CS encompasses a wide range of participatory levels such as: crowdsourcing where citizens are asked to participate with ideas, proposals, and opinions in the realisation of a project, problem-solving, or data analysis; hacker spaces (a term referring to hybrid spaces) in which citizens have the opportunity to cross-fertilise, design, and share their knowledge, and; citizen socio-linguistics, a practice in which social groups share their own idioms, linguistic facts, and the functioning of verbal language. In these and other ways, CS enables scientists and citizens to become co-producers and co-discoursers acting jointly to broaden the understanding of problems, to seek possible solutions to overcome them, and to participate in the decision-making process (Kythreotis et al., 2019). This is not mere public engagement, but catalytic and transformative policy-making actions (Kythreotis et al., 2019) in which citizens are directly involved in the process. The sociologist of science Sheila Jasanoff (2003) introduces the concept of civic epistemology whereby scientists and citizens as subjects are engaged in the ongoing process of acquiring scientific knowledge that is then certified by the scientists themselves. According to Jasanoff, scientific knowledge needs to be expanded through the involvement of citizens, which is considered a necessary condition for residing in the risk society (Beck, 1989). Thus, it becomes imperative to create a context in which citizens are encouraged to activate experiences, skills, and competences to make valuable contributions to problem-solving (Cerroni & Simonella, 2014). During these initial decades, CS primarily focused on data collection and on its definition in terms of epistemology, objectives, and networking. More recently, it has come to be considered a paradigm that supports the blurring of the boundary between society and scientific research by involving the general public in using scientific tools and methods to address socially relevant issues.

In this manner, science is becoming more inclusive with and for members of the social community, allowing for the sharing of practices and experiences. Scientists can benefit from the assistance of citizens and their knowledge of specific topics or fields, while individuals from non-academic scientific backgrounds have the opportunity to participate and “learn from within” in the process of generating scientific knowledge (Campos et al., 2021). Therefore, CS should be seen as an innovative phenomenon that is builds on the rich history of amateur science worldwide. It has the potential to generate significant discoveries and shape the trajectory of various lines of research (Chari et al., 2019). Furthermore, given the recent advancement of digital technologies, the online dissemination of scientific data, and the use of specialized digital tools, CS can be explored by various disciplines in and outside the academic world, and can also provide active citizenship and digital skills to both young people and adults.

Research methodology and objective

CS is an approach that fosters citizen empowerment and contributes to reshaping the nature of research in the context of Responsible Research and Innovation (RRI) (Sutcliffe 2011; Wickson and Carew, 2014). Moreover, it allows for a reconsideration of the relationship between science and everyday life as experts directly engage with the needs of communities, and non-experts are involved in data collection and sometimes analysis. This represents a new model for the co-production of knowledge aimed at the understanding of phenomena that operate on both micro (local) and macro (global) scales (Crain et al., 2014; Kullenberg & Kasperowski, 2016).

The aim of this contribution is to encourage reflection on the innovation that CS can bring to science communication. What is the relationship between CS and science communication? Can CS be considered a source of innovation in the communicative relationship between experts and non-experts? In order to answer these questions, this paper will use qualitative research techniques, starting with a review of recent scientific literature, and then focus on the context provided in a series of interviews.

Literature review

Alan Bryman (2012, p. 110) states that "the process of literature review is an uncertain path of discovery, in the sense that one can never know in advance where it will lead". It allows the researcher to understand what is already known about a topic and to identify gaps in the research. In this way, the consultation and systematisation of recent scientific contributions on the topic of CS helps to ensure that research work is well-conceived and more likely to be successful. As far as the link between CS and science communication is concerned, it is useful to use a literature review to first reconstruct this connection. In Europe, the connection can be traced back at least to the 1980s when the Royal Society produced a report entitled "The Public Understanding of Science", which was interpreted as a "better understanding of science that can be a significant factor in promoting the welfare of the nation, raising the quality of public and private decisions and enriching the life of the individual" (Irwin, 1994, p. 16). However, the results produced by the projects that were carried out showed little interest in actual scientific topics and too low a level of "scientific literacy". The results were strongly criticised on many levels, which is why the Public Understanding of Science model was ultimately referred to as a "deficit model". As Massimiano Bucchi and Federico Neresini (2008), both sociologists of science, explain, the deficit model was defined as such because it relied on a linear communication structure based on a top-down relationship according to which "scientific communication assumes that knowledge is fixed and transferable from the scientist (the sole holder of certified knowledge) to the citizen" (Cerroni & Simonella, 2014, p. 141).

During the 1990s, a number of studies emphasising the emergence of new forms of interaction between scientists and the lay public (Bucchi, 2003), sought to overcome the assumption that the general public is incapable of understanding science as conceived and generated by the scientific community. The aim of these new forms of interaction was to develop a pact between science and society that would better reflect the current needs and values of society (Leshner, 2003). Such a pact would be achieved through activities linked to an interacting pattern of science communication around public engagement, the underlying assumption being that "public engagement can, in general, be described as any activity in which a specific role is envisaged for citizens or stakeholders in research and innovation processes" (Ravn & Mejlgaard, 2015, p. 8). This implies that society itself would be involved in the research process through various methods, including events open to the public, communication projects, science education courses for schools, and participatory democracy initiatives. In this way, public engagement becomes a process of dialogue and participation between the public and organisations that make decisions that have an impact on people's lives. It becomes a method for organisations to build trust and consensus, and also to obtain information and feedback from the public. One of the main criticisms that has been levelled at this model is that its proponents, rather than pursuing the goal of the involvement of and deliberative debate with as large a proportion of citizens as possible, often use it to influence public opinion in order to avoid conflicts over controversial issues (Bucchi & Neresini, 2008). In fact, the growth of science education does not prevent the questioning of scientific and technological advances. For this reason, politicians and scientists have found it necessary to adopt other types of democratic approaches. The approach used by CS projects, in particular, should be seen as an effort to go beyond the characteristic model of public engagement as it places a strong emphasis on the role and rights of citizenship in order to restore public confidence in science and technology and thus to invigorate science communication. In this sense, CS can make science more accessible and engaging for a wider public. According to Wagenknecht et al. (2021), CS is a transdisciplinary approach that responds to the current science policy agenda by supporting open science and drawing on a range of science communication tools.

In CS, communication and research are viewed as areas that need to intersect through the entire scientific process, not just at certain points or at the end of the project. According to Wagenknecht et al. (2021), science communication in CS projects has two objectives: the first is to ensure the success of a project, and the second is to improve citizens' awareness and understanding of diverse scientific issues and to motivate them to take action on these issues. Effective scientific communication is synonymous with attracting participants and ensuring that volunteers are given the information and tools they need to make a meaningful contribution. In order to be effective, communication with a specific group should take place during all phases of the project (Mcleod et al.,1999) and adapt to the actors and contexts involved. Magalhães et al. (2022) believe that that there is no one-size-fits-all approach to CS projects and communication strategies toward stakeholders. According to Giardullo et al. (2023), the key advantage of CS is its ability to broaden the range of stakeholders involved in scientific research at many levels. The tendency exists to interpret communication as only a dissemination activity, rather than as a tool that can promote appropriate encounters based on communication with potential participants. More than just communicating science through public involvement, CS also enables science to be actually done (Hoover, 2016). Lipinski (2015) recommends that discussions (and thus communication) within projects between experts and non-experts should be horizontal. Gascoigne et al. (2022) believe that this suggests a more participatory form of science communication where citizens are involved at each stage of the project right up to policy co-production. In this way, science communication combined with CS, and implemented at multiple levels, involves a shift of power and the emergence of responsible research and innovation, and thus promotes the transition from "science in society" to "science with and for society" (Gascoigne et al., 2022). Although there is little literature on the innovations and transformations that CS can bring to science communication, initial studies in the literature indicate that scientific topics do become more understandable and sometimes even enter the everyday lives of citizens. According to Wagenknecht et al. (2021), CS often leads to successful science communication because it promotes a view of teaching and learning that is different from traditional perspectives in science communication. In particular, it opens up the research process to external actors, and thus communication takes place between heterogeneous actors from different contexts. With CS, science communication moves away from the traditional model of unidirectional knowledge transfer toward a participatory mode of sharing scientific knowledge and co-creating information (Wagenknecht et al., 2021). This process involves different groups collaborating and sharing new and sometimes surprising information with each other, and creates new perspectives on communication. For example, CS can help build trust between the public and science because it supports the idea of science as a social activity. This can help create a society that is more aware of science and more committed to solving scientific problems. Norström et al. (2020) emphasise the importance of well-implemented science communication in fostering a two-way exchange of information, or co-production of knowledge.

It is also important to emphasise that digital innovations have allowed for the greater accessibility of scientific information through the quick and easy sharing of scientific content on dissimilar online platforms. For instance, online data sharing has facilitated scientific collaboration and the growth of open notebooks, online repositories, and open access journals that disseminate scientific results (Grand et al., 2010, Cranshaw & Kittur, 2011). Digital technologies – such as apps installed on smartphones, dedicated portals to directly submit photographs, functions that facilitate reporting activities and the sharing of measurements and observations of animal or plant species – are one of the main factors supporting the growth of projects and the increase in the number of participants in CS programmes (Haklay 2015, 2013). The adoption of open science practices allows for greater transparency and the participation of non-specialists (Catlin-Groves, 2012; Grand et al., 2010). In particular, digital communication plays a key role in CS as it enhances the connection between citizens and researchers, and their ability to share information and collaborate in the collection of scientific data. Online platforms have created opportunities for people to build relationships and exchange information quickly and efficiently (Ellison et al., 2011), and new opportunities for work and collaboration in the scientific sector (Brynjolfsson & McAfee, 2011).

Research techniques

CS promotes the development and exercise of a range of skills and responsibilities related to research for all members of society (Schade et al., 2021). Its potential value extends to scientific and socio-political implications. This has created a paradigm shift away from previous interpretations of issues related to the public understanding of science (Magalhães et al., 2022) to a different form of science communication. In order to address our research questions, we made a choice to integrate the literature review with the direct experiences of representatives of CS projects in Italy. Representatives were identified through the reasoned choice sampling of scientists identified through mapping, who became project referents. In reasoned choice sampling, participants are not chosen probabilistically but rather on the basis of certain characteristics (Corbetta, 1999).

In social science disciplines, mapping can be used to represent a range of topics including interactions among people, groups, and organisations, patterns of human behaviour, and social changes over time. It also enables the graphic representation of data or information and the dissemination of research results to a wider audience (Wasserman & Faust, 1994). In the case of this contribution, fifty projects were identified that were active between 2019 and 2023 in Italy. Although some of them operated under the patronage of the European CS association ECSA, there is no comprehensive database of active and inactive Italian projects and their areas of research. Therefore, the list of mapped projects was provided by Citizen Science Italia. During the mapping exercise, we collected, in addition to partner institutes, information about coordinating institutes and their geographical context, and the names of the contact persons of the Italian projects identified. It was at this point in our research that we realised it would be necessary to deepen our investigations with interviews. The interview technique consists of an interaction between two subjects, an interviewee and an interviewer, for cognitive purposes, provoked and conducted by the interviewer on the basis of a questioning scheme submitted to a variable number of subjects chosen through a survey plan (Marradi & Fideli, 1996).

Twenty-three semi-structured interviews were conducted on the Google Meet platform, which allowed the researcher to go into the field without a rigid theoretical framework that might undermine new insights useful for our research (Goode & Hatt, 1962). The interview outline was designed to learn about the innovations that CS can bring to science communication. The dimensions underlying the interview outline included motives for, advantages or disadvantages of working with citizens, and also how experts interact and communicate. The importance of communication for experts, and scientists in particular, was confirmed. The media alone cannot be channels of efficient and truthful information, and there is a growing need to counter scientific illiteracy which is one of the main drivers behind the spread of fake news and anti-scientism. Each interview was transcribed in order to complete a textual corpus and then analysed. The hermeneutic approach was adopted for analysing interviews in this study. With the hermeneutic approach, meanings are externalised and transformed into objective elements within an external reality that is intersubjectively constructed (Berger & Luckman, 1974), and emerging themes are identified and delineated to which interview responses are then linked.

The following is a partial list of interview subjects:

- David Bianco: I-Rosalia project referent, biologist, works at Management Authority for Parks and Biodiversity Eastern Macro-area Bologna.
- Alessandro Campanaro: contact person for the InNat (platform) and LIFE ESC360 project, researcher CREA-Council for Agricultural Research and Analysis of Agricultural Economics.
- Anna Maria Mannino: biologist, researcher at the Department of Biological, Chemical and Pharmaceutical Sciences and Technologies of the University of Palermo, contact person for the Aliens in the Sea project.
- Antonio Riontino: scientific communicator at the University of Bari, expert in eco-sustainability and marine ecologist, contact person for Nature from the Window project.
- Massimo Scandura: zoologist, associate professor at the Department of Veterinary Medicine of the University of Sassari, Mammalnet project referent.
- Stefano Scalercio: researcher at CREA-Council for Agricultural Research and Analysis of Agricultural Economics and in charge of forest biodiversity, Butterfly Monitoring Scheme project referent.
- Andrea Sforzi: zoologist, President of the Citizen Science Italia Association, director of the Maremma Natural History Museum, reference person for From Museum to Museum, Wild Cat, Nature on the Walls projects.

Analysis of interviews

Science communication and CS are two important activities that have the potential to make science more accessible and participatory. For this study, interviews were conducted with participants who are already part of the phenomenon under investigation, and thus possess direct and profound understanding due to their privileged positions (Corbetta, 1999). Specifically, the interviewees are the coordinators of Italian CS projects who have conceived and developed the projects. The first and most important conclusion drawn from the conducted interviews is that internal communication must be evaluated and emphasised before methods of scientific communication are contemplated. Internal communication is essential to ensure the proper functioning and overall success of a project. Internal communication is an ongoing process that must to be tailored to each project's requirements and its audience. With careful planning and implementation, internal communication can be a powerful tool for achieving a successful project outcome.

> "Communication is fundamental but curiously enough it is not only fundamental on the part of those who organise and implement a project as it relates to citizens' involvement but also fundamental within the project. A typical shortcoming that some projects have is that the people working on the project, to put it in a brutal way, think they are putting something together as if it were a kind of product to sell and then they go and find buyers. I mean I do a project that is aimed at a group of people and then I try to publicise it so that these people participate, but maybe I don't give enough importance to internal communication. That is: what are the expectations of the people working on the project? What are the limits? I have said that the components I need to do a citizen science project are having the scientists who know about that field, a professional communicator, a sociologist, and everyone has to do their job, and everyone contributes to setting up something that will work. If there is no dialogue or if people on the project staff are not satisfied, are not happy, are not taken into account, are not listened to, do not communicate properly and do not receive communication, a project cannot work. So there has to be a 360-degree communication, internal and external." (Andrea Sforzi)

Internal communication in CS projects refers to communication efforts between research team members, project coordinators, and participants involved in the collection and analysis of scientific data. According to many of the interviewees, communicating properly means having certain expertise and skills that experts/scientists often lack. Scientists and researchers tend to be minimally engaged in the dissemination of results and public information activities (Pellegrini & Saracino, 2016). CS can be a tool to engage in sharing, building, and designing resources and knowledge.

> "The scientist certainly has to communicate with the public, because communication is a part of our job, but, unfortunately, we are neither trained nor used to doing so. Few scientists are effective in communication. Most tend to communicate only with the scientific world. They are unable to translate the fruits of their work in a simple way and therefore fail to communicate precisely because of this inability; that is, they fail to use simple language that people can understand. And many other scientists don't communicate because they basically don't care about it. I mean maybe they don't care about publishing their studies or their careers, don't care that much about how much their studies could really affect society and improve the world. From this point of view, citizen science is a bit of a gym because launching a citizen science project forces you to communicate with the world of ordinary people and also to differentiate communication according to its type, and the profile of the audience." (Massimo Scandura)

> "I have the idea that you need communication professionals first and citizen science should not be just a little phrase that makes a project cool. I am convinced that it is a really good tool and that it should be analysed in substance, and then we need to understand what were the conditions when it worked and what were the conditions when it didn't work." (David Bianco)

The centrality of science in modern society calls for greater interaction between the scientific community and the general public, which is why science communication has become extremely important. CS is a tool that has the potential to bring improvements to this area, above all in ways that science can become available to citizens and citizens can become genuinely aware of a wide range of issues.

> "It's clear that without communication you can't reach people, and because it's right that people should be made aware of what's going on, science has to open up. Today I have to say that a lot of progress has been made in this direction. There's a desire to open up the scientific world, research, science, and discoveries to ordinary people, to citizens, and citizen science is certainly a tool for that. With citizen science you're looking for help from citizens, but on the other hand you're opening up to citizens [...] Because the

> citizen in some way is also made responsible. So, it's not just that I give you the information, but I also put you at the centre of the information. So, I give you the news, but I also put you in a position to grow culturally and in terms of awareness. And sometimes there is growth on both sides, because you realise that the citizen can give you a lot." (Anna Maria Mannino)

> "Communication is a job that wants to clear that famous wall that exists between academics and citizens, and citizen science is the ideal tool because from my point of view, environmental communication was fine in the 1990s but today we are hungry for experience, no? We need to do things and so the person who comes to a conference only follows for an hour, and after that they don't follow you anymore. If, however, citizens get involved in the collection of data, and it is really an action that produces reports, data, etc., then you are really able to change some of their beliefs. Citizen science is the new weapon to change things." (Antonio Riontino).

The openness of science is currently going through a phase of reshaping and renegotiation (Dickson, 2008), in part thanks to the engagement of citizens in science and technology issues in a variety of projects around the world (Blok, 2007; Gavelin et al., 2007). In this sense, CS has begun to play a significant role in the formulation of public policies in various fields.

> "It is so, so important to communicate science, especially to convince those with all the shopping bags to invest in research instead, because once citizens are involved and you open up to a larger audience of possible voters then the politician more easily opens the doors of spending. So at least from our point of view, the most important thing is that there is greater [public] awareness and that paradoxically the citizen educates the politician, in the sense from the bottom up…" (Stefano Scalercio)

> "The critical issue may be that of not devoting enough time and expertise to the recruitment of and communication to volunteers. Training is fundamental and if it is not done [well], the results may be inadequate. Validation [is also important] so be careful to always validate volunteer data, to make sure they are still volun-

> teers. Data must still be correct because the primary objective is scientific." (Alessandro Campanaro)

Citizens who become aware of their local area and other specific issues may have a completely different views than experts. Their knowledge can contribute or even lead to new understandings of such issues. This concept was first formulated in the field of European environmental policies in 2008 (Haklay, 2015), when it was recognised that such an approach would allow for the inclusion of citizens' perspectives in the face of global challenges.

Conclusion

The qualitative interview technique made it possible to investigate research questions, adding value to the review of relevant literature. It was clearly established that the practice of CS constitutes an approach capable of optimising the data acquisition process for researchers. However, it is also crucial to note that this approach requires a rigorous verification and validation phase in order to ensure the reliability of the information collected. In addition, CS represents a channel through which citizens can gain a deeper understanding of specific scientific issues. This learning is not only manifested through the use of active participation in practical activities but finds its fullest expression in the implementation of carefully designed communication strategies. CS, therefore, constitutes a milestone in the evolution of the relationship between the scientific and social spheres, also serving as an invaluable vehicle for scientific communication. This form of engagement allows participants not only to share their experiences and insights, but also to address a broader and more diverse audience. Through the promotion of public engagement within the dynamics of scientific research and the subsequent dissemination of the results obtained, the practice of CS and scientific communication are combined to facilitate greater understanding, awareness, and appreciation of scientific disciplines by a broad public. Science currently has one of the least intense inclusion processes when compared to other social subsystems (Burzan et al., 2008), but by advocating the need for more openness and participation in science, CS addresses some of the challenges in science communication (Wickson & Carew, 2014). At the onset of the COVID-19 pandemic, communication played a key role in providing citizens with information and guidance on how to minimise the risk of infection. These forms of communication and involvement require openness on the part of all stakeholders, both experts and non-experts, and a commitment to the responsibilities and tasks that come with these roles (Hecker & Taddicken, 2022; Salmon et al., 2021).

CS, therefore, constitutes a practice that has the potential to reconfigure the paradigm of science communication to non-specialist audiences by employing new modes of engagement. Scientists need to communicate directly with citizens and get closer to the general public by leaving their ivory towers. At the same time, CS brings an innovative element to the empirical research conducted by scientists, both in the field and in non-experimental settings. A future area of development for this investigation could focus on the activities undertaken by participants in CS projects and their communication strategies. Such an analysis would aim to determine whether CS can constitute a key element of innovation within the science communication process.

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Assessing the Assessment of European Researchers' Night: Findings from a Nationwide European Researchers' Night

Introduction

Science communication initiatives are becoming more and more widespread across the world (Trench & Bucchi, 2021). They are accompanied by national and international policies designed to support these efforts and continue to bring science and the rest of society closer together (Weingart & Joubert, 2019). However, little attention has been paid to the assessment and reporting on the real impacts of these initiatives and policies (Weingart & Joubert, 2019; Ziegler et al., 2021).

The European Researchers' Night (ERN) is a long-standing initiative (started in 2005) funded by the European Commission through the Marie Skłodowska-Curie Actions. It comprises a series of events that take place annually on the last Friday of September across Europe and beyond, and which are designed to promote science and research. In addition, ERN aims to "increase awareness amongst the general public of the importance and benefits of research and innovation and showcase its concrete impact on citizen's daily life" and to "heighten young people's interest in science and research careers" (European Commission, n.d.(a)). In 2019, ERN reached 1.6 million visitors in four hundred different cities (European Commission, 2020a). In 2020, the number of visitors increased to two million (European Commission, n.d.(b)). Most ERN events are organised by institutions or consortiums that have been awarded competitive grants for the purpose by the European Commission. "Main events can last up to two full days", and build-up events "can also be organised prior" to the main events with activities that include "hands-on experiments, science shows, simulations, debates, games, competitions, quizzes, etc." in order to promote "the European dimension, gender balance, and inclusion in research and innovation" (European Commission, 2020b). In 2021, ERN events took place on September 24th with the European Green Deal as the main topic. The budget for the events was eight million euros (European Commission, 2020c).

Despite its wide timeframe and the growing number of participants, published empirical research on the impact of ERN remains scarce (Roche et al., 2017). As a result, ERN and other similar events have long been criticised for their lax approach to assessment and evaluation (Bultitude et al., 2011; Kennedy et al., 2018; Weingart & Joubert, 2019).

The European Commission funding requires the impact assessment of ERN activities but, as there are no specific assessment guidelines, each consortium develops and implements its own strategy. Moreover, results and strategies emerging from this process are rarely shared. Thus, it is very difficult for the science communication community to build on each other's experience with previous ERN events.

In 2021, we were involved in a Horizon 2020 project for ERN in Portugal. Under the project REGGAE (Researchers for European Green Growth and Education), we assessed the opinions and perceptions of three different stakeholders in the event: participants, scientists involved in the planning and implementation of activities, and organising institutions. In this way, we managed to collect valuable data and feedback regarding the initiative.

Here we present our findings regarding the participants' experience of ERN 2021, and from there reflect on the overall impact of the ERN assessment strategy. We believe the approach to ERN assessments needs to be reshaped. In order to work towards this goal, we reflect on the insights and drawbacks of our own experience assessing a nationwide ERN initiative and on what could make assessing ERN more valuable to organising institutions, science communication scholars and practitioners, as well as to the European Commission. With these reflections, we hope to contribute to a wider discussion about why we are assessing ERN and what we expect to achieve from our assessments. Only then will it be possible to devise a strategy for how to make these assessments. We believe that by exploring the purposes of ERN assessments, it will be possible to set useful guidelines for future ERN assessments (and science communication initiatives, in general). By defining tangible objectives, it will be possible to produce comparable results, which over time will also contribute to the effective assessment of the initiative's goals. At this point, it is important to note that for the purposes of this chapter "objectives" are defined as short-term, tangible, and more easily-assessed, and defined in relation to each science communication initiative. "Goals" are defined as the long-term objectives of initiatives, such as ERN, and reflect continuous efforts aimed to produce significant changes in participants (attitudes, knowledge, etc.).

Above all, we argue that data regarding events as well as their assessment and their results must be shared amongst practitioners, scholars, and funders in order to enable the transparent overall evaluation of the longest-lasting science communication initiative in Europe, fostering evidence-based science communication practice, and contributing to the science of science communication. Although our reflections here are mostly focused on the perspective of ERN participants, we believe it is necessary to consider all relevant stakeholders when designing common guidelines for a robust assessment of ERN.

The REGGAE consortium

The REGGAE Project was proposed and implemented by a consortium of three institutions with extensive experience in public engagement activities, ranging from structured formats of public debate to mobilisation and mutual learning activities and co-creation. The REGGAE consortium had been involved in previous ERN projects, specifically Futuro 2020 (in 2013) and Foresight 2030 (in 2016 and 2017).

The leader of the consortium was Ciência Viva, the Portuguese agency for scientific and technological culture. Created in 1996 to promote public awareness of the importance of science and technology at a national level with a particular emphasis on young people, Ciência Viva coordinates a national network of science centres spread across Portugal. In 2021, nineteen Ciência Viva centres organised ERN events and pre-events.

The other consortium partners are the following two research institutes operating in the field of the life sciences both with a high profile in science outreach: the Instituto de Investigação e Inovação em Saúde (i3S), an association of three institutes engaged in health and life sciences research of the University of Porto, and; the Instituto de Tecnologia Química e Biológica António Xavier (ITQB NOVA), a research institute of NOVA University Lisbon, dedicated to life sciences, chemistry, and associated technologies. Within the REGGAE Project, i3S coordinated the communication work package and ITQB NOVA coordinated the assessment package. Both institutions also organised their own ERN events and pre-events.

Activities

In total, REGGAE involved twenty-one institutions organising science outreach events across Portugal. All of the participating institutions organised a main event on Friday, September 24, 2021 (twenty-one main ERN events) as well as a total of eighty-eight build-up events in the preceding months. Overall, the 109 ERN events attracted over 12,500 participants and involved around eight hundred scientists.

The planners of ERN activities in 2021 faced the additional challenge of the uncertainty of the COVID-19 pandemic. From the start, it was planned that REGGAE included both face-to-face and remote events. Face-to-face events would also include a remote component, and there was an alternative plan to go fully remote if further COVID restrictions were implemented. Fortunately, this was not the case, and the only restrictions were the required use of masks and limitations on the number of people in closed spaces.

All events were disseminated through a dedicated website (https://nei.cienciaviva.pt/2021/), and social media accounts, and through the media outlets of the consortium's institutions and local partners.

Build-up events explored different formats, such as talks, hands-on activities, demonstrations, guided visits, or workshops. However, most of the REGGAE main events resembled science festivals as do many ERN initiatives (Jensen et al., 2021). According to Bultitude et al. (2011) a science festival is a "time-limited and recurring" event that focuses on "science, technology, engineering, and related aspects", and seeks to "engage non-specialists with the scientific content" through activities with a "common theme and/or branding". All REGGAE main events used the same graphic design in disseminated content and other onsite promotion materials. The Green Deal topic proposed by the European Commission was the main focus of all events. Events took place inside or in the vicinity of the science centres, the research institution (i3S), and in a marina (the event organised by ITQB NOVA).

Assessment strategy

The assessment strategy had two main dimensions: the participants and the researchers involved in the activities. A third focal point were the event organisers, here referred to as the institutions.

In this chapter, we will focus specifically on the results generated from the feedback of participants. First of all, we wanted to know who the participants were, what made them come to an ERN event, and what their experience was once there. The analysis of participants included the views they expressed about science and scientists.

The methodology of the REGGAE events assessment involved gathering data from over a hundred events at twenty-one different institutions. In terms of impact assessment, build-up events were mainly testing grounds for the main events. These tests allowed us to improve both the assessment instruments and the instructions for institutions implementing them, and also to define feasible targets for survey response rates at the main events.

Data collection instruments comprised questionnaires (for participants, researchers, institutions), interviews (for researchers), and other methods (for participants). We prepared both online and paper versions of the questionnaires to accommodate all possible situations.

The full data collection protocol was submitted to and approved by an Ethics Committee. Organising institutions received an instruction manual detailing how to apply the different instruments. All assessment documents (questionnaires,[1] guidelines,[2] results,[3] and Ethics Committee approval[4] are available in the respective links).

1 https://www.itqb.unl.pt/ern-2021-participants-questionnaire
2 https://www.itqb.unl.pt/instructions-manual
3 https://docs.google.com/spreadsheets/d/1mtYguGH6I7AgdchgH6wmTP3Rzk Z5MSzC/edit?rtpof=true&sd=true
4 https://www.itqb.unl.pt/ethics-committee-approval

Questionnaires

Participants

We consider a participant anyone sixteen years old or older attending the event as a visitor. Participant questionnaires were made available to organising institutions in three formats: through the Mentimeter app (www.mentimeter.com), as a Google Form link, or as a PDF file to be printed and distributed. All formats had the same questions presented in the same order. Institutions could choose which formats were most adequate for their event, resources, and target audiences. We encouraged the use of Mentimeter because it is a user-friendly platform and allows for live-display of the results at the venues, which we hoped would encourage participation. The questionnaires were designed with the aim that participants would fill them out themselves (although some institutions had staff to help perform that task). To encourage participation, respondents could leave their email in a separate form and enter a raffle to win a Family Ticket to enter any Ciência Viva Centre in the country.

The items chosen for the participants' questionnaire aimed at assessing the general success of the events and the attainment of ERN's goals, including those related to the European Green Deal. We sought to understand whether people enjoyed their experience and how it contributed to improving their attitudes toward science and scientists, promoting scientific and research projects or institutions, and encouraging younger people to pursue scientific careers.

Researchers

In this study, we defined researchers as those invited by the organising institutions to design activities or interact with participants during an ERN event (researchers who were there only as visitors were considered participants). In compliance with GDPR, no email contacts were shared with the assessment team. Instead, we asked organising institutions to forward a Google Forms questionnaire to the researchers involved in their own events. In contrast, institutions had no access to individual responses. The questionnaires were anonymous but identified the venue. At the end of the questionnaire, researchers available for a follow-up interview were directed to a second unlinked Google

Form where they could leave their email address. As mentioned above, we will not discuss the researchers' responses in this chapter.

Institutions

We also developed a questionnaire for the institutions organising the events to assess their view on the initiative and the assessment strategy itself. Although we do not explore those results in detail here, we do mention some important insights drawn from them.

Follow-up interviews (researchers)

To complement the information collected in the researchers' questionnaires, we invited ERN researchers to a follow-up interview. One week after ERN, we invited willing researchers to a Zoom interview. We adopted a semi-structured interview format with a script to guide the conversation. Two people conducted the interviews and took notes. The individual sessions were recorded with the explicit consent of the interviewees and later transcribed and anonymised. As mentioned above, we do not discuss the researchers' dimension here.

Other data collection methods

Aware of the difficulties of collecting data via questionnaires in this type of events, we wanted to test other assessment methods that might be more interactive and entertaining for participants. We opted to focus on collecting participants' opinions about specific topics and proposed two additional data collection instruments: dotmocracy and post-it walls (explained below). Organising institutions were free to decide whether to use these formats during their events. We provided possible questions in the instruction manual for institutions.

Dotmocracy is a method where participants answer different questions by placing a sticker (or token) indicating their desired answer for a single or multiple-choice question or by using colours to give different answers to a particular question (e.g. red – no; yellow – maybe; green – yes). The outcome is a board in which the place (or colour) of the tokens represents the participants' perceptions.

The post-it wall is a similar method but for open-ended questions. In this case, participants answer the questions by writing their answer on a post-it and placing it under the question. The result is a colourful wall presenting participants' thoughts and opinions.

In both cases, participants are asked to collaborate in the construction of an aesthetically pleasing board that contains information regarding their opinions, perceptions, or attitudes.

Summary of results

The first conclusion we drew from our assessment was that that REGGAE events were a success as measured by stakeholders' satisfaction. We received very positive feedback from institutions, participants, and researchers, and found no significant differences in data collected at different venues.

Here, we focus on the results obtained for the participants at the main ERN events organised by REGGAE on September 24. We collected 666 participant questionnaires during the twenty-one main events. Overall, these events attracted approximately 6,500 participants of which we estimated 4,200 were sixteen years old or older (and thus were eligible to answer the questionnaire). This corresponded to a 16% response rate. With a few exceptions, the number of responses was proportional to the number of participants at each event.

Participants rated their experience at ERN very positively (median of 9 out of 10) and most were willing to participate in future editions of the event. Participants responded that they had fun, and had the opportunity to interact with scientists and learn more about science and technology (Figure 1). Furthermore, they became more aware of how science works, its importance, and its role in their daily lives.

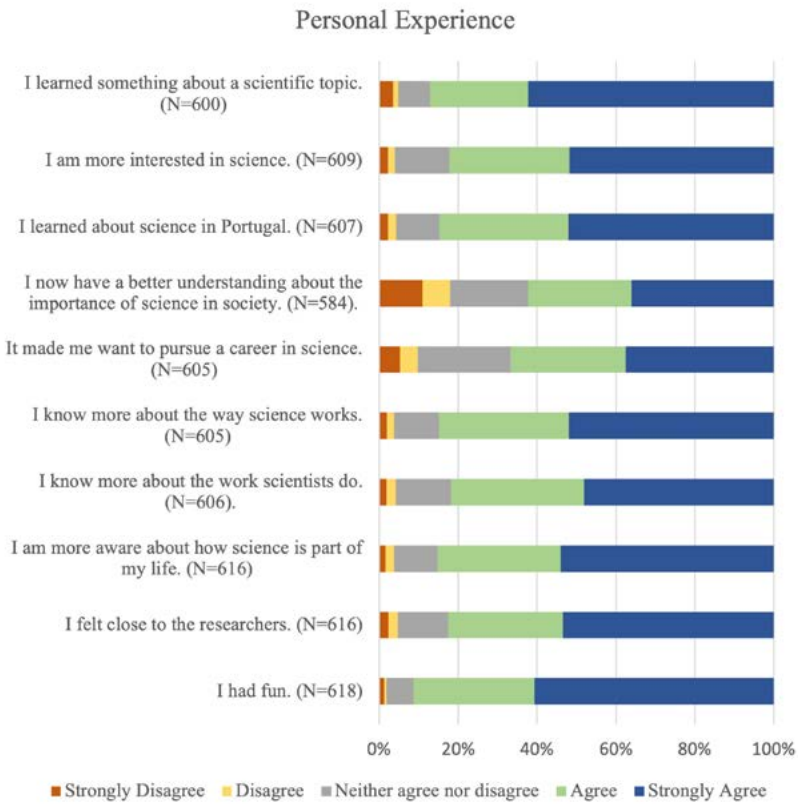

Figure 1: Distribution of respondents by level of agreement with each statement concerning their personal experience at ERN2021

Most respondents were female (62%), which is an overrepresentation of the female proportion of the national population (according to the Institute of National Statistics, in 2021, 52.4% of Portugal residents were female). This is not surprising as women are more likely to attend such events, usually with their children (Mazzitelli et al., 2019). In some cases, women have also been found to be less likely than men to refuse to answer questionnaires (Groves & Couper, 1996).

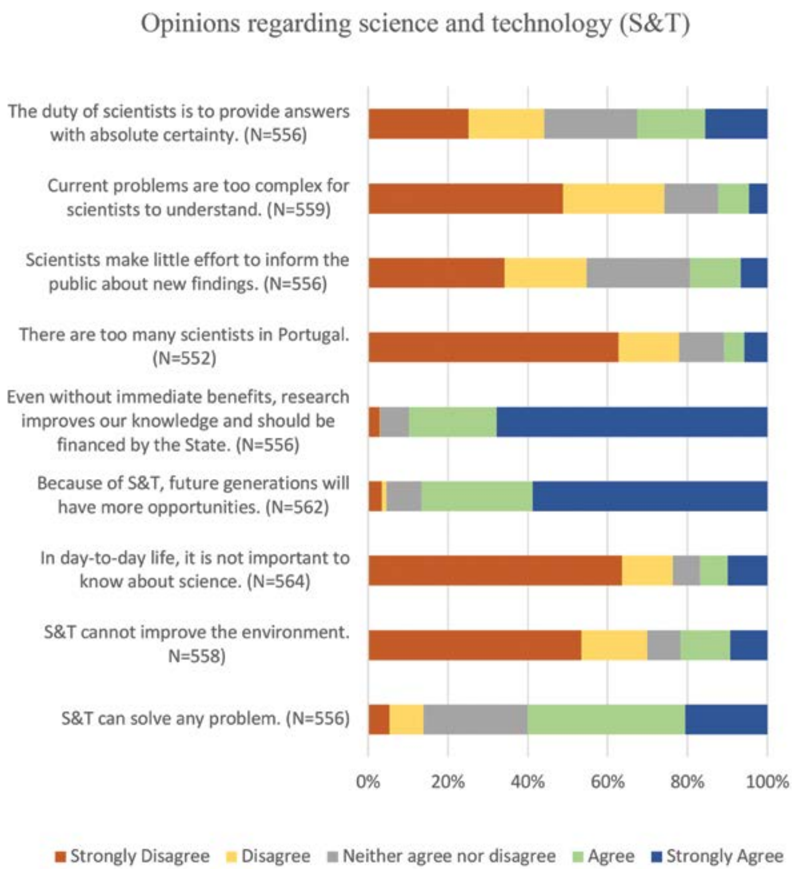

Figure 2: Distribution of respondents by level of agreement with each statement

In terms of age, age groups 16-24 (24%) and 35-54 (49%) are overrepresented compared to their proportion of the national population (10.6% and 28.4% respectively). It is likely that many respondents were young people interested in science and technology and exploring a career within the scientific field (21% of respondents were students of scientific fields), or parents accompanying their children to the event (71% of the respondents were attending the event with friends or family or accompanying children).

The participants' profiles tended to match those reported at other science festivals (Kennedy, Jensen, & Verbeke, 2018). Namely, they were highly educated (68% had at least a bachelor's degree compared to 21% nationwide), and/or had a professional (23% of respondents) or personal connection to science (61%). More than half had visited the hosting institution before, indicating previous experience with similar events, which is characteristic of attendees of science communication events.

In general, participants had a very positive image of science and scientists (Figure 2). They recognised the importance of research and scientific knowledge and showed great confidence in the ability of scientists to understand and tackle current problems. This positive perspective of science is perhaps even exaggerated as many participants expressed the belief that science can solve any problem (60%), and that scientists should always provide answers with absolute certainty (33%). These overly confident views or wishful thinking could be understood in the context of the COVID-19 situation in Portugal in September 2021, and the fact Portugal had a very successful vaccination campaign with 95% of the population voluntarily vaccinated against SARS-Cov2.

ERN participants tended to regard themselves as being very interested in scientific topics related to the environment (average self-rating of 8.8 out of 10) and moderately knowledgeable (average of 6.9 out of 10) with the self-rating of knowledge beingly slightly more widespread.

The data collected through other methods confirmed and complemented these results. For example, the dotmocracy board used at the event in the Oeiras marina (Figure 3) showed that respondents believed that "science will find solutions for the environmental crisis" (75% answered yes, no one answered no) or that the "investment in science should be higher" (100%). These results are not surprising given the generally positive opinions about science expressed by respondents, and the personal or professional links to science and technology identified above. Moreover, an additional question highlighted that most participants had met at least one scientist before. Nevertheless, meeting a scientist was a first-time experience for 14% of the respondents. A fourth question addressed how the COVID-19 pandemic affected respondents' confidence in science: 45% stated that it had increased, and

55% that it did not change (we assume because it was already high, given the results described above).

Figure 3: Dotmocracy used at ERN2021 at the Oeiras marina. Eighty-two visitors gave opinions. The questions were: "Will science find solutions for the environmental crisis? Yes/Maybe/No" (top, left); "Investment in science should be: higher/the same/lower" (top, right); "Did COVID-19 affect your trust in science? Yes, it increased. / It did not affect it. / Yes, it decreased." (bottom, left); "Had you ever interacted with scientists before ERN2021? Yes/No" (bottom, right)

A post-it wall at the Ciência Viva Centre in Vila do Conde (Figure 4) revealed what people enjoyed most about the event: ("I enjoyed hearing the bats." "I enjoyed seeing the bats.") and that they learned something new (such as how big bats are or how they communicate). It corroborated the positive views on science with respondents choosing positive adjectives to describe the event (e.g. "fantastic", "interesting", "fun" …). In terms of what participants enjoyed the least, only eight gave input, four of whom reported there was nothing they disliked. These results are similar to what the questionnaires revealed.

Figure 4: Post-it Wall used in Vila do Conde. The questions were: "What did you enjoy the most?" (top, left); "Three words you associate with science." (top, right); "Something you did not know before your visit." (bottom, left); "What did you enjoy the least?" (bottom, right)

Challenges of the assessment strategy

Implementing an assessment strategy for so many events with the involvement of so many institutions posed many challenges. Each institution is different, having different conditions, staff, and resources, which makes it difficult to ensure a harmonious data collection process. We tried to minimise discrepancies by providing assessment protocols while also allowing some flexibility for local adjustments.

Data collection during events such as science festivals is difficult. Participants are there to have fun, meet researchers, learn about new projects, ask questions or give comments; they do not want to fill out extensive questionnaires. In our questionnaires, we tried to limit the questions to those that would contribute to our two main aims: assess the success of ERN as an event, and tackle some of ERN's more general impact dimensions as defined by the European Commission (promotion of scientists and research, raising awareness of their importance, attract young people to careers in science). All the same, as pointed out by a few participants and by the organizing institutions, the questionnaires were too long.

Data collection decisions were also constrained by legal and ethical issues. We opted for a conservative approach and avoided posing sensitive questions, such as economic status or ethnicity, to participants (asking about ethnicity is illegal in Portugal). Judging by the educational and professional status we observed, the economic status data would probably have further confirmed the participant profile found at similar events – specifically, middle and upper class (Kennedy et al., 2018). As for ethnicity, in Portugal, there are no official national statistics and, although it was much debated, the official census in 2021 did not include that information. Instead, we opted to ask respondents if they considered themselves to be a member of a minority (12% answered in the affirmative). This response may account for different situations as respondents will use their own definition of minority in their particular context (nationality, ethnicity, sexual orientation, etc.).

We also decided not to collect data from children. The General Data Protection Regulations (GDPR) requires parental consent for the collection of personal data from children under sixteen years old, which would have been difficult to obtain in the ERN event settings. While we could have found strategies to circumvent this limitation, we believed it was more important to assess older teenagers (sixteen and older) who would soon have to make choices about their studies and future careers rather than introducing additional instruments. We did collect data on how many children participated in the activities (a conservative estimate of 2,275) and have plenty of observational evidence on how much they enjoyed the events.

Finally, there is an intrinsic limitation to assessing the impact of ERN in terms of the goals set by the European Commission. It is unlikely that a single event, such as ERN, changes a person's career choice or views on science and technology. It is even more difficult to measure such changes with any on-site assessment instruments. To gain insight into those issues, we propose, instead, an effort to define stable data gathering strategies that would assess the evolution of ERN audiences (and ERN researchers) over time.

How can we move forward?

Our knowledge of science communication has been evolving as the field has been growing both as a practice and as a discipline (Bucchi & Trench, 2021). However, according to Gerber et al (2020), there seems to be a clear gap between practitioners and scholars created by the failure to recognise each other's needs, aims, and priorities. There is also a third variable in this equation – the funders (in this case, the European Commission).

Simultaneously, there seems to be a disconnect between the motives and goals of science communication and its practical impacts (Weingart & Joubert, 2019). Despite aiming to bring together science and the rest of society, most science communication activities seem to be reaching always the same people (Kennedy et al., 2018). Our results confirm this phenomenon, with ERN participants being highly educated and having an existing interest or connection to science. This means other segments of society are excluded from these initiatives, perpetuating the overall social exclusion of underprivileged groups (Dawson, 2014). Participants in science communication initiatives usually demonstrate previously existing positive attitudes toward science and researchers, and are more likely to take full advantage of the products and knowledge that science generates. However, if we, as science communication practitioners, believe that all citizens should have access to science in its many forms, we must strive to reach those who feel they are not welcomed by these initiatives. Improving assessment will help us gain better insights about who is missing and why, learn from initiatives that attract the non-converted, and develop new strategies to engage other target groups with science.

We are fully aware that it is not possible to introduce significant changes in knowledge, much less in attitudes, regarding science (and most topics) with single activities or events such as ERN. Still, each science communication activity or initiative contributes to the definition of the participants' relation to science and scientists. Assessing, documenting, and sharing knowledge about the impact of such activities helps us understand what works and what does not, what we can change and what we cannot (or should not). To be fair, the European Commission does request the documented assessment of funded ERN initiatives, but there are no general guidelines for how this assessment should be done nor are impact reports are available.

Sharing information

From our perspective, one major obstacle for the impact assessment of ERN is the lack of information from previous editions. With very few results published and no assessment protocols available, each consortium has to design its own activities and assessment strategy instead of building on previous tried and tested methods. This seems like a waste of valuable resources and data. With eighteen years of funded ERN initiatives so far and several countries involved accounting for several millions of participants and thousands of researchers, with minimal standards for the collection of data, the dataset would be enormous by now.

Sharing assessment protocols and results is a crucial step toward a better understanding of the overall impact of ERN. Like other projects funded by the European Commission, funded ERN initiatives should be required to have data management plans, describing how data will be collected, anonymised, and stored in accordance with FAIR principles (Findable, Accessible, Interoperable, and Reusable). We envisage a central database where results are uploaded, but until such a system is available, each consortium can make its own databases available, starting from a minimum set of standards to a more robust framework for science communication datasets. The value of having all of these results accessible would be enormous and would foster analysis by science communication scholars. However, in order to make this feasible and above all productive, it is necessary to define an assessment strategy that allows for the collection of data amongst all institutions in a standardised manner, which would facilitate comparisons between ERN initiatives and over time. The definition of this strategy requires the following steps: 1) setting objectives and goals to be assessed; 2) designing instruments to collect data; 3) understanding the type and nature of the data produced, and; 4) sharing the data and results of the assessment. Ideally, we should aim toward creating a centralised data centre that contains the assessment strategies and all data generated from different ERN initiatives in a standardised, accessible, and comparable manner.

Of course, comparisons need to be sensible. Different initiatives in different countries, or even within the same country, will necessarily produce different results. To generate useable conclusions, it will be necessary for databases to include detailed descriptions of the conditions in which the data was collected, such as the type of event, the location, and other relevant information. Finally, as Ziegler et al. (2021) also believe, the evaluation of ERN or any science communication initiative must "not replace academic impact research" because it is not the place, nor the time for that kind of research.

Agreeing on goals and objectives

The most important and complex step is to agree on why (or what for) we are assessing ERN. The value and use of impact assessment data will necessarily vary according to its user. Practitioners will most likely focus on a more strategic view of assessment such as how the data can be used "to improve the visitor experience and increase the impact of the interaction" (Barriault & Pearson, 2010), to increase the number or diversify the profile of participants, or even to come up with more cost-effective methods for activities. In parallel, the European Commission, as funder, may wish to assess the return on their investment in terms of science policy goals. Finally, scholars would be able to gain insights into ongoing science communication activities, learn more about ERN audiences or scientists, and contribute to a grounded discussion with practitioners about new directions for assessment strategies and the initiatives themselves. Although some objectives and goals of the three parties coincide, others do not. It will be impossible for an assessment strategy to fully meet all these needs, and certainly compromises are necessary. We suggest defining minimum requirements for a robust impact assessment and designing modular assessment instruments, which may be combined, allowing for flexibility.

Through ERN, the European Commission aims to promote science in general and research projects, demonstrate their importance and benefits to society, and attract people to scientific careers. However, these long-term goals are influenced by many other factors, which makes them complex, and thus difficult (if not impossible) to attain with one-off events and their success hard to measure. Aiming to make a direct assessment of ERN goals is therefore unrealistic. When answering questions about changes in attitudes and knowledge, for example, respondents may be infatuated by their presence at the event or give answers that they believe the institutions wants to hear (Jensen, 2014), which may lead to overly optimistic and inaccurate data. If we want to improve the assessment of ERN initiatives, we should start by reframing goals and designing realistic, tangible, and measurable objectives.

The assessment of a European-wide activity calls for the definition of a European-wide assessment strategy, which can only be obtained through collaborative reflection involving funders, practitioners, and researchers from different fields, in particular social scientists "whose expertise will remain relevant to measuring impact and developing strategies for effective science communication" (Ziegler et al., 2021). Rather than changing ERN's overall goals we need to accept that each ERN initiative is a step towards long-term goals and also a part of a broader spectrum of public policy measures and science communication activities. Each step should have more specific and measurable objectives. To get a better grasp of the true impact of these initiatives, we must learn to identify the "small steps" that move us toward long-term goals (Besley et al., 2017). Having realistic and tangible short-term objectives will also help science communicators (and researchers) design more targeted activities and later learn from the assessment results. For example, we may not be able to assess whether participation in one ERN event changes a respondent's perception of science and technology, but we can find out whether ERN was their first opportunity to talk to a scientist or the first time they were in contact with a specific field. We may not be able to assess if ERN changes a researcher's perception on the importance of listening to the public, but we can find out if they learned something from the audience during participation.

Agreeing on design and assessment methods

After agreeing on objectives and goals, the next step is to agree on assessment methods. Even if all past ERN results were shared now, comparisons over time and between countries will be very difficult if there are no common data collection instruments. Once we settle on the desired impact and on what are we aiming to assess, we can define suitable tools to assess how successful ERN initiatives have been from several points of view. Moreover, if we can agree on (at least some of) these tools, we can have standard and consistent guidelines for assessing ERN as suggested by many scholars (Roche et al., 2017). We are not proposing a one-size-fits-all survey, but rather a combination of instruments targeting distinct information needs so that following these guidelines would provide a better overall picture of "what" happens and "who" participates at ERN events, and how ERN contributes to continuing building a bridge between science and the rest of society.

Assessment instruments do not need to be restricted to questionnaires, and indeed should include other quantitative and qualitative methods. Above all, assessment should not overwhelm either participants or practitioners. By combining different methods, we would be able to avoid lengthy questionnaires even if sacrificing some information.

We propose dividing the participants' assessment into three dimensions: 1) the attendee's profile; 2) their satisfaction with the experience, and; 3) their perceptions and attitudes about science.

In an event such as a science festival, for example, dimensions 1) and 2) could be assessed by questionnaires directed at a random sample of the population. Short questionnaires that are easy to implement, quick to analyse, and ensure anonymity. Dimension 3) could be assessed with other data collection methods, such as dotmocracy or post-it walls, which could be conceived of as an additional activity in the festival and could potentially involve all participants.

Questionnaires would provide stratified information about the audience and their experience at the event while not taking up too much of their time. Simultaneously, audience members' opinions about science and scientists would reflect a more general view of the participants. This would also facilitate obtaining data from children without collecting personal information.

There are also disadvantages that come with this division, namely the inability to cross opinion and attitudes data with the profile of participants. Moreover, the number of questions that may be posed using boards is limited. Otherwise, the whole venue would be filled with opinion boards that would ultimately interfere with the objective of promoting interaction with science and scientists.

Nevertheless, one must accept that ERN events are not the best setting for such social studies nor is that the point of impact assessment. Learning about the public perception of science is the aim of Eurobarometers and similar studies, which are designed with that purpose. For ERN assessment, just learning about "who" attends the event and how different audience segments experience the events can be extremely valuable. If we can obtain in addition a general view about the audience's opinions, we also gain insights on participants' opinions about specific science and technology topics, helping us to fine tune future initiatives.

Being able to collect quantitative and reliable data about the audience and comparing it to local statistics can help us to assess if we have reached the desired target audience, who is being left out, and what could be done to tackle that shortcoming in the future. Comparisons over the years will show how ERN audiences are evolving. Comparisons between venues or countries may identify new strategies and highlight blind spots in our overall efforts.

We believe that simpler, standardised assessment strategies will have many benefits: cost-effectiveness, feasibility, comparability, and representativeness. With simpler and easier data collection tools, we should be able to collect more (and more honest) responses and increase the response rate. Further qualitative data could be collected with on-the-spot interviews with participants and through systematic observation. In our experience, not all institutions have enough resources to devote to these tasks but could nevertheless benefit from the data collected at other places when designing their activities.

Conclusion

We are at an important crossroads in the relation between science and the rest of society. Climate change, the COVID-19 pandemic, nanotechnologies, and artificial intelligence represent challenges that require a public discussion involving all stakeholders in society (Trench & Bucchi, 2021). Science communication will be pivotal in this transition and, if on one hand, the efforts and investment have never been greater, on the other we are not yet capable of properly assessing their true impact.

ERN is one of the biggest international science communication initiatives (if not the biggest), and yet, despite the millions of euros in investment, the thousands of researchers and hundreds of institutions involved every year, there is no access to the data collected, and we lack a clear perspective of what this data should entail. Failing to address these needs means we cannot build on years of experience gathered all over Europe, and that we will make preventable mistakes. Joining efforts will contribute to collective growth and the improvement of ERN in general and, as a consequence, increase its impact. And we do not need to reinvent the wheel because the foundations to define a suitable assessment strategy for these communication efforts have already been developed in other fields. All we need to do is take one step back, learn from what has already been done, transfer this knowledge to the growing field of science communication, and use this to take several significant steps forward.

Better assessment of ERN will provide valuable information. It will allow us to learn from ours and others' experiences to improve the quality of these initiatives. Moreover, it will produce sufficient and meaningful data that will allow the European Commission to justify annual investments in ERN and other initiatives. Finally, it will provide valuable insights allowing scholars to continue developing our knowledge of the field, and over time this will improve our ability to implement successful and meaningful activities.

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Communicating Quantum Technologies in an Era of Mistrust and Misinformation

Introduction

In this paper, we tell the story of a community effort to bring widespread quantum awareness to the general public through scientific outreach. The project, entitled Quantum Technologies Education for Everyone (QuTE4E), emerged from a large practising community of educators, academics, and industry representatives in the field of quantum technology with over four hundred members from forty-five countries. Coordinated by a dedicated action intended to unite disparate efforts across Europe (Quantum Technology Education – QTEdu), eleven pilot projects were established to address quantum technology education for universities, industry, high schools, and the public. QuTE4E was among the most ambitious of all the pilot projects, with the core aim being to develop guidelines for public communication of Quantum Science and Technologies, pioneering a research-based approach we call Physics Outreach Research (POR).

We believe that all citizens, regardless of background, position, and educational experience, should have the opportunity to be made aware and be inspired by Quantum Technologies (QT). Technologies such as quantum computing, simulation, sensing, and communications are already changing the world, for example, developing highly precise medical imaging (MetaboliQs, 2018) or materials that capture carbon dioxide (Wei et al., 2020). Public awareness of this field is essential for two reasons: first, because inspiration is the seed from which the future quantum workforce is recruited, and; second, because the individuals who are or will become policymakers, work at start-up companies, or hold public offices must know the implications of QT, rather than considering them distant concepts with no real application. In the present period of mistrust and misinformation around emerging technologies, aptly called the "post-truth" era ("The Challenge of the Post-Truth Era", 2018) a research-based methodology to deliver outreach for emerging technologies such as QT is essential.

To develop practical guidelines for communicating QT to the public, researchers in the pilot project first needed to answer the following questions:

- What are the main challenges that need to be overcome in order to optimise outreach efforts?
- Which ideas and content should we include in our "story"?
- What should be our narrative approach to outreach, our "storytelling"?
- What kind of tools can educators use to support this storytelling?
- How can we reach the widest audience in practice?

In assessing the challenges and content necessary for outreach, the pilot ran a Delphi Study to obtain community input, which is described in Section II of this paper. After that, a storytelling framework was developed, culturo-scientific storytelling (CSS), which is described in Section III. The CSS calls for the use of engaging tools to support the scientific-thinking process, the most effective of which are described in Section IV. In Section V, we discuss the implications of CSS for developing an awareness of Responsible Research and Innovation (RRI) in the public. Finally, in Section VI, we conclude with an overview of the increasing scope of outreach in the field of QT, and lessons learned from the pilot project on how to conduct it most effectively.

Community input: challenges and content

The first step in developing practical guidelines for outreach is to understand what they need to cover. By identifying the primary challenges for outreach, we were able to research and suggest methods to overcome them. Knowing exactly which topic areas constitute the best use of the highly limited time of educators and science communicators is also essential, and we therefore addressed all of these questions in the QuTE4E Delphi Study. The study ran between September 2021 and June 2022, and aimed to gather insights from practitioners in the field of outreach and education for QT on the most effective ways to engage with different stakeholders and the most important content to include in outreach efforts. (For the full details of the study, see Seskir et al., 2023.) Below we summarise the method, results, and key implications for QT storytelling.

The Delphi method, developed in the 1950s, is a structured process for obtaining expert opinions on a specific topic (Dalkey & Helmer, 1963). It involves a series of rounds in which experts are asked to provide their thoughts on a set of questions, with the responses from each round used to inform the next. This iterative process allows for a more comprehensive and nuanced understanding of the topic as it enables the integration of a wide range of perspectives into not only the responses, but also the questions themselves. In the QuTE4E Delphi study, a group of experts from the pilot project itself were invited to participate in the preliminary round. This was followed by two more rounds, which were open to the general public but mainly circulated within the QTEdu and associated networks. In the final round, thirty-six participants from seventeen different countries participated. Two examples of how questions evolved with expert feedback between the preliminary and final rounds are shown in Table 1.

Table 1: Example of evolution of questions between the preliminary and final rounds

Preliminary round questions	Second (final) round questions
What kind of important problems will there be for the outreach activities in quantum technologies in the following five years?	Please rate the potential problems in terms of severity for the outreach activities in quantum technologies that may be encountered or still persisting (in the next 5 years).
Which essential concepts of quantum physics should be utilised for outreach activities in quantum technologies?	Please rate the concepts/approaches provided below in terms of their usefulness to be utilised for outreach activities in quantum technologies.

Challenges for QT outreach

In the preliminary round of the study, participants were asked open-ended questions prompting them to provide their suggestions for what they considered to be major challenges in the field of QT outreach. The experts in the first round were then shown these responses, and additional items were added by them. In the final round, the larger group of thirty-six participants were asked to rank by severity the nineteen challenges provided to them in the previous rounds. As the field is evolving rapidly, we considered two separate time frames: the present, and more than five years into the future. Results are shown below, normalised so that the highest-rated problems are assigned a value of 1.00

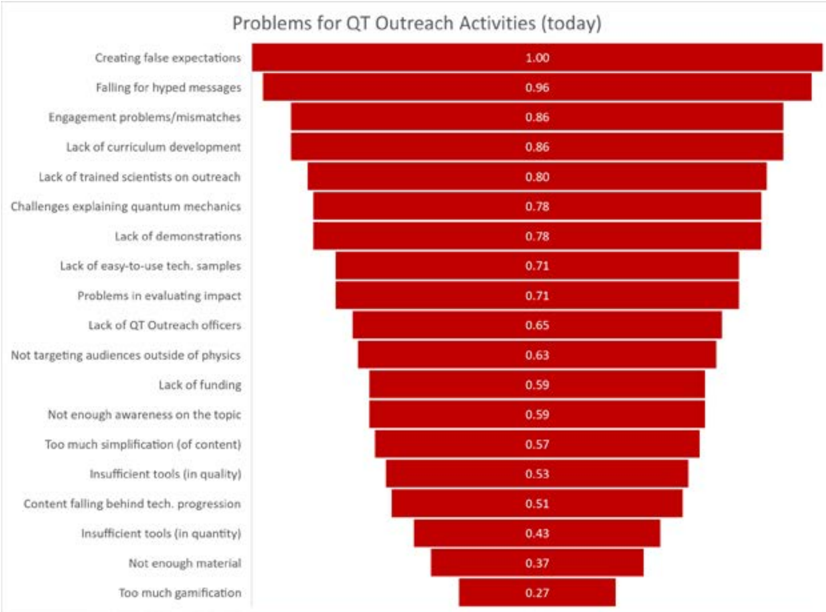

Figure 1: Challenges for QT outreach activities (present time), as ranked by participants in the final round of the QuTE4E Delphi study

Here we note several interesting findings relevant to practical storytelling. First, there is the concern about creating false expectations, which can lead to disappointment and erosion of trust. Second, there is a risk of falling for hyped messages and misinterpretation by non-expert audiences, which can hinder understanding and progress. Both of these challenges call for outreach activities that are grounded in reality and show the real-world applications of the technology. Third, there are engagement problems and mismatches between the communities working in this field and their intended audiences, which can hinder effective communication and outreach efforts. Fourth, there is a lack of curriculum development for different target audiences, which can make it difficult to effectively educate and engage these groups. Finally, there is a lack of trained scientists who are skilled in outreach activities and methods, which can limit the impact and effectiveness of outreach efforts. These problems can be addressed with more dedicated efforts in QT outreach. Indeed, these issues are not unique to the field of QT, but are present in many scientific fields. In the present age of misinformation, we must find new ways of communicating science to the public (Fähnrich et al., 2021). We believe that Physics Outreach Research (POR) and the modus operandi of the QuTE4E pilot project will significantly contribute to resolving these issues.

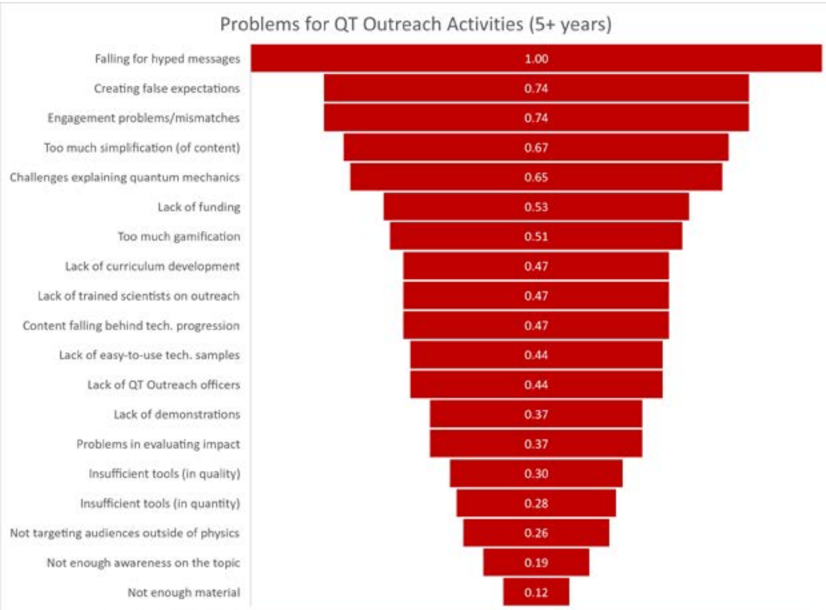

Figure 2: Challenges for QT outreach activities (five+ years into the future) ranked by participants in the final round of the QuTE4E Delphi study

Content for QT outreach

The second primary area of the study was focused on the perceived usefulness of various concepts and approaches for use in QT outreach activities, thus enabling practitioners to construct a narrative for outreach activities with specific topics in mind. As for the challenges, we first asked experts to suggest the topics they thought most important (in the first two rounds), and then asked participants to rank them by importance in the final round. The eight most important concepts as provided by EU and non-EU participants are shown below. In order to analyse their position within the narrative to be deployed, we used a conceptual tool known as the discipline-culture (DC) framework, first posited by Tseitlin and Galili (2005) to structure disciplinary knowledge. Here we describe it briefly and refer the reader to Goorney et al. (2022) for its use in structuring outreach activities.

It is clear that scientific fields have their own distinct discourses and narratives. This is obvious from just the titles of textbooks, courses, and journals, (Griffiths, 2005; Copenhagen University, 2022; IOP Publishing, 2013). It is only necessary speak to a scientist in a different field to experience that what feels like an entirely different language is being spoken. Tseitlin et al. likened these disciplines to cultures with a history of development, a plurality of approaches and viewpoints, and an uncertain and evolving future – just like cultures in our society. In its approach, science may be considered a dialogue between interacting discipline-cultures, analogous to the conglomeration of cultures that make up our modern world.

In each discipline-culture there exists a *nucleus* of core concepts and key paradigms which define the discipline, a *body* of working theories and daily applications of scientists, and a *periphery* of alternative ideas and viewpoints. An example of a concept in the nucleus is that of Quantum Superposition – the idea that no object has a definite state until it is measured, and rather exists as a superposition of many possible states. The body in the DC of quantum physics hosts concepts such as the qubit, the quantum equivalent to the binary digit with which computer calculations run.

Quantum physics is known mainly for having numerous interpretations. It is possible to count no less than sixteen (Cabello, 2017), many of which engage the public's fascination, such as the Many Worlds Interpretation and Quantum Darwinism. While most of these are not in regular working use by scientists in the laboratory, they certainly contribute perspectives to the discipline-culture, and thus can be considered part of the periphery.

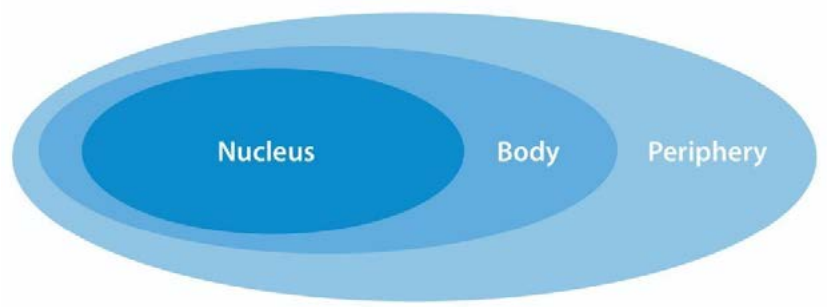

Figure 3: The discipline-culture framework as conceived and adapted by Tseitlin and Galili (2005)

Below we present the eight most important concepts for QT outreach as ranked by the participants of the Delphi study and placed in the discipline-culture framework of quantum physics. They are labelled by nucleus/body/periphery in Table 2. (See Seskir et al., 2023 for a full discussion of the implications of these results.)

Table 2: Top eight concepts/approaches to be utilised in QT outreach activities, rated in terms of their usefulness and adapted from Seskir et al., 2023

EU	Non-EU
Superposition (nucleus)	Superposition (nucleus)
Measurement (nucleus)	Measurement (nucleus)
Quantum state (nucleus)	Quantum state (nucleus)
Qubit (body)	Entanglement (nucleus)
Entanglement (nucleus)	Qubit (body)
Technological concepts (like quantum computers) (body)	Interference (body)
Interference (body)	Probability amplitude (nucleus)
Probability amplitude (nucleus)	Technological concepts (like quantum computers) (body)

The most striking result is that participants considered concepts in the nucleus of the DC (core principles of quantum physics) to be the most valuable for outreach. Those in the body of the DC (applications of core principles) were considered the next most important, and those in the periphery last. We believe this highlights an important disagreement in community opinion which must be addressed. The principles in the nucleus, while clearly valuable for inspiring the fascination of the public, are also highly prone to miscommunication and not necessarily representative of the daily experience of quantum technologists. Furthermore, we also believe there is also great value in activities in the periphery of the DC, which is supported by educational research and described in the next section. These results demonstrate the importance of clear guidelines being widely disseminated to practitioners.

Theoretical framework: Culturo-Scientific Storytelling (CSS)

Equipped with key concepts to include and problems to overcome in communicating QT, we may now consider with greater granularity how to structure outreach activities. An essential question to ask is: what outcome do we want from non-formal education? For what purpose do we communicate science? There are many benefits to doing so, such as raising awareness (Tarín-Pelló et al., 2022), preventing misinformation (La Bella et al., 2021), and inspiring future generations of scientists (Vennix et al., 2018). In this context, we are inspired by the work *Five Minds for the Future* by Howard Gardner (2008), in which he considers the *minds* required for the public to navigate and contribute to modern society. These minds must be disciplined, synthesising, creative, respectful, and ethical. We believe that public communication, with carefully crafted storytelling, may be contribute to the development of such minds.

In particular, Gardner's minds are inherently addressed in the everyday activities of scientists through the so-called inquiry cycle (Kuhn, 2011). Engaging in scientific thought is precisely the disciplinary thinking to which Gardner refers, and aspects of experimentation, conceptualisation, and theory-building related to such thinking develop synthesising and creative minds (Gardner, 2008). Scientists with an awareness of the need for responsible research and innovation (RRI) such as openness, inclusivity, and diversity, engage the ethical and respectful minds. Thus, promoting scientific thinking among the public through outreach may provide a great benefit in developing the skills needed to contribute to an ever-changing "society of acceleration" (Rosa, 2010). Goorney et al. (2022) collectively call these skills culturo-scientifc thinking, and believe they include elements such as disciplinary thought, creativity, and awareness of the fragility of scientific knowledge.

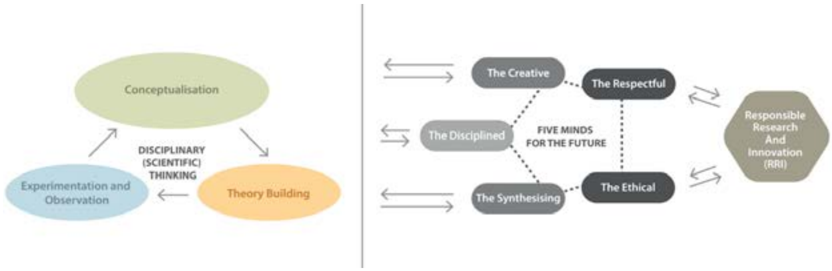

Figure 4: The approach taken by the QuTE4E pilot to develop Gardner's five minds through scientific thinking and RRI

CSS, the theoretical framework for a storytelling that best develops these skills, is summarised here (for more detail, see Goorney et al., 2022). While culturo-scientific storytelling was developed in and to promote QT, we note that it is a general framework for public communication of all areas of science and technology that are rapidly developing, such as Artificial Intelligence (He et al., 2019), cryptocurrency (Joo et al., 2019), and the Internet of Things (IoT) (Nižetić et al., 2020). We provide a summary of this method below for the use of educators.

First, we propose that activities be designed with the scientific inquiry cycle in mind. They should enable development of the disciplined, synthesising, and creating minds through application of experimentation, observation, conceptualisation, and theory building. Furthermore, we suggest that activities are designed with a sequential storytelling structure in which participants are taken on a journey through the field of QT. In order to structure this journey, we again make use of the discipline-culture framework as conceived by Tseitlin and Galili (2005).

Beginning in the periphery, where the most engaging and puzzling aspects of the field lie, is an effective hook and replicates the experience of a scientist encountering an idea that pushes the boundaries of their knowledge. Next, activities should be based around the nucleus, giving participants a paradigm through which to frame the subject. In

QT, topics in the nucleus include the notion of superposition, and the wave-particle duality nature of light (Weissman et al., 2019). Appreciating whichever of these core principles are relevant enables activities based in the body to be conducted, which consist of the applications of these ideas. For example, awareness of the superposition principle may enable explanation of quantum scenarios, such as interferometry and double-slit experiments.

Activities in the body allow participants to make predictions, test them, and build working theories in the scientific inquiry cycle. Finally, we suggest that finishing activities in the periphery is invaluable for developing culturo-scientific thinking skills. This gives participants exposure to the reality of the scientific experience – that no knowledge is ever complete, and the DC may grow and shift over time with new discoveries. These skills, including futures thinking (Levrini et al., 2021), epistemological awareness (Plakitsi & Kokkotas, 2010), and scientific thought (Chiofalo, 2022) are invaluable in the post-pandemic "society of acceleration" (Rosa, 2010) in which we currently live.

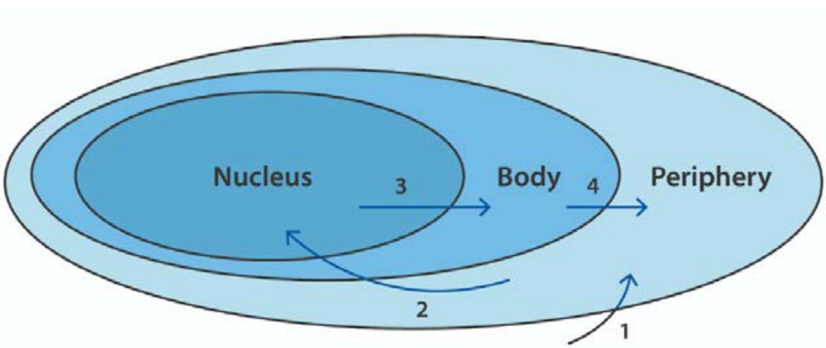

Figure 5: The culturo-scientific narrative approach explores the discipline-culture (a) in a journey reflective of the experiences of the scientist whereby each topic is addressed with scientific thinking, (b) in a journey constituted by an introduction with knowledge in the periphery (Arrow 1), later to be formalised into core principles in the nucleus (Arrow 2). Working applications can then be discussed and understood in the body (Arrow 3), before returning to the periphery to emphasise the evolving, incomplete nature of the DC (Arrow 4).

Participatory tools for storytelling

Implementing CSS requires that the participants be treated as scientists themselves. Yet how can this be accomplished when experimental QT setups require millions of euros to create? Addressing this need, members of the QuTE4E consortium and the wider community have developed and trialled a host of tools which can make implementing CSS practical. These toolboxes include resources which support experimentation, creativity, and formalisation. (For an extensive overview of this, see Seskir et al., 2022, p. 17). Here we show some examples of the tools developed within the pilot project, as a demonstration of the possible features of QT outreach activities designed with CSS.

Providing representational competence: The Quantum Odyssey

One major challenge for engaging scientific thinking in members of the public is being able to provide them with a foundation for understanding concepts in the nucleus and the body of the DC when they have no mathematical or scientific background. Let us consider the example of quantum gates and algorithms, the working basis (in the body of the DC) of quantum computation. An experienced physicist has a certain internal perception (or representation) of how gate operations work. This could be in the form of a visualisation, such as an arrow rotating around the Bloch Sphere, or a series of mathematical operations (Goorney et. al, 2023).

Visualisation software can be a powerful means to quickly provide participants the representational competence they need to understand a concept. In the case of Computation, the software Quantum Odyssey[1] is a self-paced learning platform which utilises a unique, fully visual method of displaying quantum gates and state vectors. Developed by Quarks Interactive through cross-disciplinary dialogue between physicists, computer scientists, educationalists, and industrial end-users, the software's aim is to tackle concerns in miscommunication about what quantum computers can do and offers a rigorous yet accessible learning space where learning how to create working code for universal quantum computers can take place.

1 Available on https://www.quarksinteractive.com/

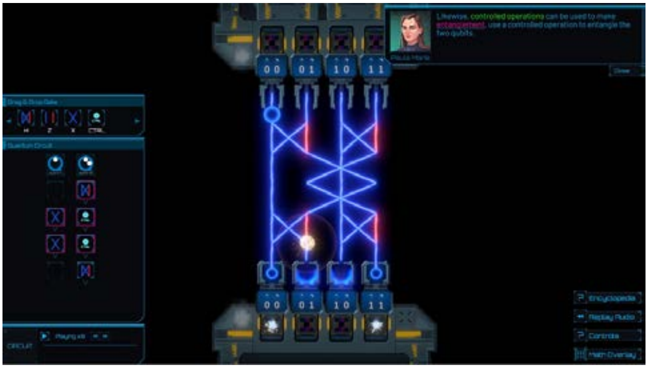

Figure 6: A snapshot from an introductory Quantum Odyssey learning puzzle. The circuit panel on the left and the Hilbert space of the circuit on the right are fully visualised. On the top right, the narration describes what is being observed. This representation of quantum gate operations is unique to Quantum Odyssey.

The software brings an original graphic version of the matrix-vector representation of the Hilbert spaces of full quantum systems. Because the translation for matrices to visual elements is exact, this representation is also exact. Indeed, advanced users can enter a “mathematics mode” and see the same operations in mathematical form. As a result, Quantum Odyssey can enable users to experience in an operational and participatory manner all of the fundamental principles behind quantum mechanics, including superposition, entanglement, and interference, and how to make use of them in constructing full proof-of-concept quantum algorithms. This means that members of the public can be guided with complete scientific accuracy through the nucleus and body of a storytelling version of quantum computation without any prior knowledge of gate operations or even fundamental principles of quantum mechanics.

Being a citizen scientist: Quantum Moves and Quantum Moves 2

Another challenge for outreach activities is providing an engaging “hook” for participants to engage with CSS. Why should they be interested in the activity? One possible solution to this is a class of tools in the field of citizen science (Roche et al., 2020), a model of conducting science in which members of the public are given the tools needed to participate in real research.

Quantum Moves (QM) and Quantum Moves 2 (QM2) are developed by ScienceAtHome based at Aarhus University (ScienceAtHome, 2012.) ScienceAtHome specialises in games and simulations in the field of citizen science (Roche et al., 2020), a model of conducting science in which members of the public are given the tools needed to participate in real research. Gamification of the tools with which the citizens interact encourages engagement and fosters participation. (Bowser et al., 2013) Thanks to the fun and intuitive nature of the games, QM and QM2 have been played over eight million times (ScienceAtHome, 2012).

In Quantum Moves, players take the role of a laser-based optical tweezer, guiding an ultra-cold atom through various challenges representing the operations of a quantum computer. The game-physics is a direct simulation of quantum mechanics, making use of the Schrodinger equation. The precise path taken through space is a class of experimental problems, known as quantum optimal control, with which physicists still grapple. Researchers using a computer algorithm to solve optimal control problems were able to demonstrate a benefit when using player-generated solutions as "seeds" over random seeding. Put simply, player solutions were able to help real researchers in a laboratory to build components of a quantum computer and conduct scientific research. Such a narrative is highly engaging for educators using the tool for outreach purposes and can provide a motivation for engaging with full CSS.

Navigating uncertain futures: The Quantum Decide Game

A final tool we would like to highlight is one that proved very popular among educators in the pilot project for its ability to engage individuals in the periphery of the DC, which is an essential component of CSS and invaluable in developing Gardner's minds. QT is generally perceived as complex, difficult, and remote, and many do not grasp the potential benefits it will bring to society. The Quantum Decide Game (QDG), developed by the Spanish photonics institute ICFO (ICFO, 2021), aims to introduce member of the public to the field of QT and its implications through a participative activity that makes use of cards as discussion artefacts. An example of one such card is below in Figure 7:

Figure 7: An example of one of the thinking cards used by participants of the Quantum Decide Game in order to foster discussion about the possible implications of Quantum Technologies

During QDG, the participants split into small groups (four to six people) that play the role of committees responsible for designing policies in research and innovation. Throughout the activity, they read, select, and discuss quantum concepts and technology, and explore cutting-edge scientific projects. The material provided underlines the importance of science and research in their lives with accessible examples. At the end of QDG, each committee reaches a strategic decision about the future of QT and shares it with the rest of the participants. The content of the cards varies from core concepts (nucleus), information about applications (body), and open discussions about issues with no clear solution (periphery), thus making it a powerful tool for implementing the CSS. Several examples of such discussions are provided in the next section. In addition, it promotes useful abilities for all citizens such as critical thinking and communication skills, and increased awareness about the current and future impact of QT on society at large.

Organising QDG for the public is simple and practical because it requires few resources. The cards that the participants use to gather information are freely available on ICFO outreach website (ICFO, 2021) in paper and digital format, and are translated into four different languages (Catalan, Spanish, English, and Italian). This makes QDG versatile and flexible, allowing it to fit into many different contexts and countries. ICFO and other institutions around Europe have used QDG to introduce quantum physics to high school students, secondary school teachers, and the general public. The simple setup makes it possible to organise it online and in person, and in many different settings (e.g. schools, museums, libraries, bars).

Feedback from participants emphasises the game's enjoyable and participatory nature, and that it allowed them to discover new concepts in an informal and engaging environment. In the Decide Game, people are not passive receivers of concepts as they are in classical outreach seminars, but are active characters that can choose information that is more relevant to them and interact with other participants to reach a consensus about what should be the future of QT.

Discussion: storytelling for the ethical and respectful

The tools described in Section IV are an effective means to engage individuals in the scientific thinking process, and thus develop the synthesising, creative, and disciplined minds of which Gardner conceived. We now discuss the implications of the CSS for reaching and developing the ethical and respectful minds through the promotion of Responsible Research and Innovation (RRI) (see Fig 4).

In February 2022, an RRI team at the University of Pisa ran a workshop for PhD students in both scientific and non-scientific disciplines as a transversal competence building activity (University of Pisa, 2022). Forty PhD students from a range of departments participated and were divided into twelve groups named after inspirational Quantum Physicists such as Marie Curie and Erwin Schroedinger. After an introduction to some of the historical development and core concepts of quantum mechanics through short accessible animations (QPlaylearn[2]), a keynote speech was delivered to tell the story about what quantum technologies are and where they are leading us. In this way, the discussion proceeded in the framework of CSS, from the periphery to the nucleus and the body of the discipline-culture.

The primary activity for the groups was based around QDG, which was specialised to address the following questions: (i) what should be the priorities of QST scientific policies in order for them to be consistent with the RRI dimensions? and; (ii) how should the above priorities be ranked? The use of guided scientific inquiry (Furtak, 2006), where-

2 Available on https://qplaylearn.com/education

by selected examples of possible implementations of the RRI dimensions in QT contexts were previously highlighted in the keynote, was a means of engaging the scientific thinking process of the participants (as highlighted in CSS, see Figure 4), even of those without any prior knowledge of the topic area. Participants were then provided with the Decision slide (see Figure 8) containing a basic set of priorities to be supported and/or changed at will. They then defined their choice of priorities, ranked them according to the RRI dimensions, and recorded the decision in a shared document according to a provided template. Finally, in the remaining half hour the different groups briefly reported their work in a plenary session. The final minutes were devoted to a discussion and question-and-answer session. The issues brought up here returned the participants to the periphery of the field, engaging with ideas and perspectives that are beyond what most scientists consider daily applications of QT.

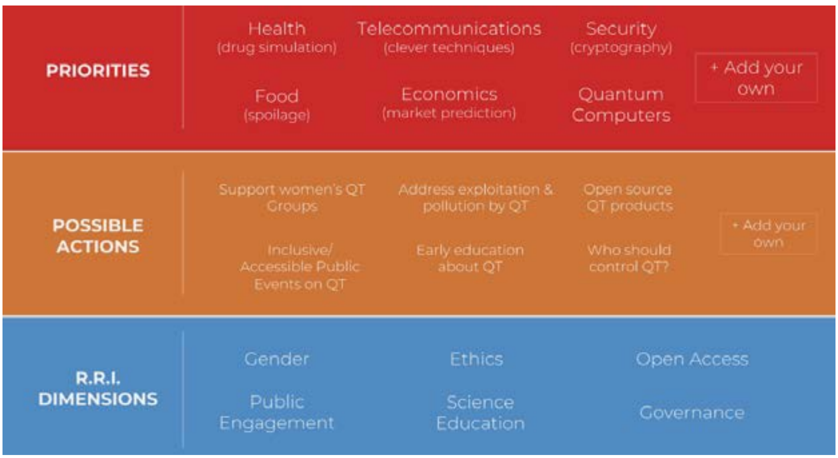

Figure 8: Guidance provided to participants of the RRI workshop based on QDG at the University of Pisa (2022)

In keeping with the spirit of RRI, training activities led to further collaborative design of a tool for developing RRI awareness and Gardner's respectful and ethical minds. The methodology used in these activities, which took place in the same PhD student workshop the following year, is inspired by "staff-student co-creation" in which learners and teachers together generate educational content for future learners. Because learners are engaged in the process of developing educational material with staff, “learning by doing”, this method has been shown to yield benefits in engagement, awareness, and enhancement of learning (Cook-Sather, 2014), Through the duration of the didactic path described above, participant groups were prompted to highlight key stories and info cards that raise important questions they might use to educate the public about the principles of RRI. Several examples of resulting discussions are shown below, and the key cards from QDG which prompted them are available in the Appendix (Figures A1–A5):

i) Is scientific funding into the “mysteries” of quantum mechanics a wise investment for society? Is it worth investing significant resources into potential applications that might benefit society only in the long-term? (Figure A1)

ii) We are already using some of the unusual properties of quantum mechanics as the founding principles of widespread common technologies, i.e. lasers, solar panels, etc. (Figure A2).

iii) We can use quantum mechanics to generate new technologies that will impact society in many different fields. It should therefore be considered a responsible investment for governments worldwide (Figure A3).

iv) Many principles of quantum physics contradict common sense. Is this a limitation of the validity of this theory? Should the public trust such a “weird” theory (Figure A4)?

v) Because most members of the public are not educated to “speak the language” of quantum physics, news outlets often generate misinformation. If this misinformation makes its way to policymakers and investors, it can do serious damage to the adoption of QT in society, which may cause us to miss out on many of the future benefits of QT, for example in healthcare and environmental safeguarding (Figure A5).

Typically, one of the difficulties of making the public aware of issues related to RRI is the lack of contextuality. Dimensions such as “open access” and “ethics” can seem distant and disconnected from everyday life without a field in which to ground them, and can thus be difficult to convey in both formal and informal contexts (Margherita & Bernd, 2018).

The QDG allows these issues to be contextualised by QT and carefully explained through story, thinking, and information cards, encouraging participants to develop the respectful and ethical minds in the process.

Conclusion

A key ongoing theme in the findings from the QuTE4E Pilot is the value of an engaging narrative in outreach efforts in order to develop the skills people need to navigate the uncertain futures brought on by the advent of modern technologies. Participatory, hands-on tools are a key to implementing CSS, and the recent work of the scientific community in this area is now extensive. The majority of concepts we consider important to communicate to the public (shown in Table 2) are accessible through the demonstration of games and interactive tools (Seskir et al., 2022). Over the duration of the pilot project, these tools and CSS were implemented in many small-scale events intended to expose the general public to the wonders of QT, such as hackathons (Quantum AI Foundation, 2022) and game jams (Internet Festival, 2021). As governments become more aware of the negative implications of public misunderstandings of new technology, QT outreach is increasingly becoming a major part of international strategies for developing the field. Overhype (Sartori & Theodorou, 2022), misinformation (La Bella et al., 2021), and widespread misunderstanding (Dignam, 2020) are several recent examples from the field of AI, which is currently undergoing a public explosion of interest.

Europe Day, held in the headquarters of the European Commission in Brussels, was a particularly large initiative (European Union, 2022). QuTE4E ran the booth representing the research and development efforts of QT in Europe, the Quantum Flagship[3]. An estimated fifteen thousand members of the general public passed through the venue where Quantum Moves 2 and Quantum Odyssey were set up and used in a participatory manner to engage members of the public directly into the periphery of the DC, and offer a discussion around the implications of the technologies they demonstrate.

In Italy, the project Italian Quantum Weeks[4] was the first national effort of its scale, intended to raise awareness of QT and help members of the

3 Available on https://qt.eu/
4 Available on http://www.quantumweeks.it

public make sense of the quantum news they may have encountered on the web, in newspapers, or elsewhere. IQWs has now run over two consecutive years, and involved more than one-hundred and thirty researchers, technicians, communicators, and teachers from over forty research institutes across seventeen Italian cities.

And finally, UNESCO is currently in the planning stages for the dedication of 2025 as the International Year of Quantum Science and Technology. This prospect is representative of the degree to which QT development will impact society, and yet it is currently significantly underknown and misunderstood by members of the public. With increasing attention drawn to QT on an international scale, it is crucial that the opportunity to communicate the field is not wasted, and that every outreach scenario is conducted as effectively as possible. The risks of drawing attention to QT, without careful thought to how to do so, are substantial (Sartori & Theodorou, 2022; La Bella et al., 2021; Dignam, 2020). QT may avoid such issues by developing large scale outreach efforts, but only if they are accompanied by research-based guidelines. We highlight that the development of such guidelines, which we call Physics Outreach Research (POR), is crucial in the current "society of acceleration" (Rosa, 2010) where technological advancements are driving rapid sociocultural reform. Such a perspective must also be adopted in other emerging fields such as cybersecurity, and particularly Artificial Intelligence. These fields may benefit from a community-based approach as the QuTE4E pilot project has used in QT.

The result of this community has been CSS (Goorney et al., 2022), and the many tools available for implementing it (Seskir et. al, 2022). In this paper, we have offered several examples of their application, and how they may develop in members of the public the disciplined, synthesising, creative, respectful, and ethical minds they need to navigate the uncertain future of a society rapidly changed by technology.

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Appendix

Quantum Decide Game discussion cards used in RRI workshop:

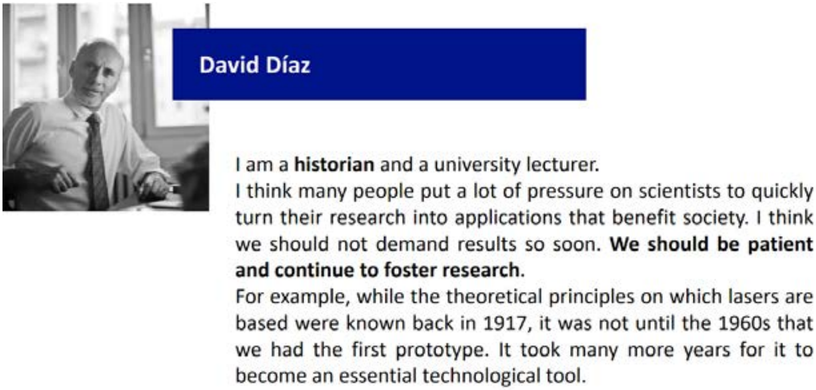

Figure A1: Is scientific funding to explore the “mysteries” of quantum mechanics a wise investment for society? Is it worthy to invest significant resources for the possibilities of application that might benefit society, but only in the long term?

Figure A2: We are already using the bizarre properties of quantum mechanics as the founding principles of widespread common technologies, i.e. lasers, solar panels, etc.

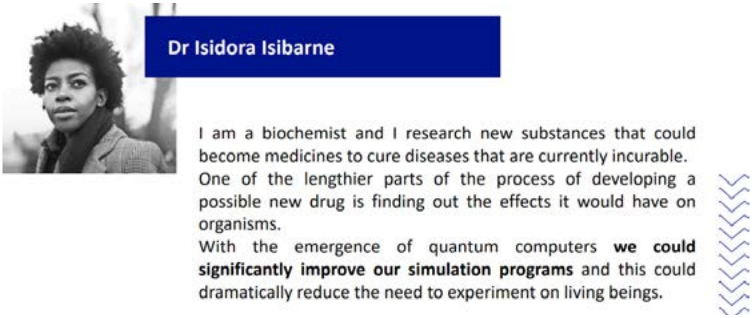

Figure A3: We can use quantum mechanics to generate new technologies that will impact society in many different fields. It should therefore be considered a responsible investment for governments worldwide.

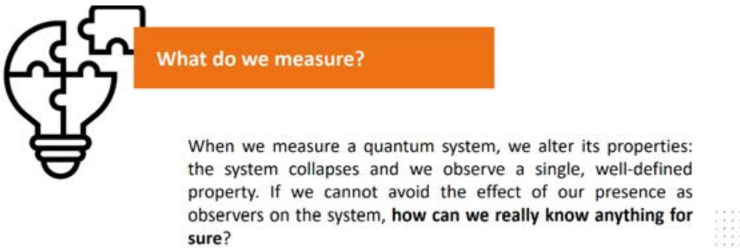

Figure A4: Many principles of quantum physics contradict common sense: is this a limitation to the validity of this theory? Should the public trust such a “weird” theory?

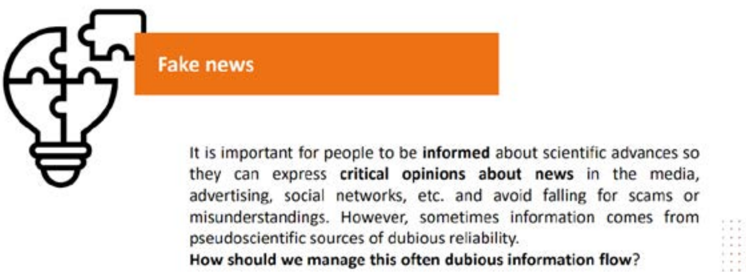

Figure A5: Because most citizens of the public are not educated to “speak the language” of Quantum Physics, news outlets can be prone to generating misinformation. If this makes its way to policymakers and investors, it may do serious damage to adoption of QT in society, which may cause us to miss out on many of the future benefits of QT, such as in healthcare and environmental safeguarding.

Fabiana Battisti and Marco Bruno

Knowledge and Irony: Binomial of the Post-Truth Era

Introduction

John Dewey stated (1929, p. 294) that: "Knowledge falters when imagination clips its wings or fears to use them. Every great advance in science has issued from a new audacity of the imagination." This assertion is reinforced when we look at the theoretical-application research field encompassing the communication of science. We consider science communication as the social conversation around science (Bucchi & Trench, 2021), and the science of science communication (Fischhoff & Scheufele, 2013) as how people deal with science and research. Combining the sociological perspective of the field of research and the imaginative dimension, it is useful to summon Cate Watson's suggestion (2015, p. 416) that "an eye for irony can [...] be considered a requisite for the sociological imagination".

In the last few years, there has been a substantial growth in social media activity concerning science, although there are many disparate practices within that growth that are difficult to systematise (Davies et al., 2021). These include the private initiative of accredited or unaccredited science disseminators (Looi & Ho, 2023) and, at the same time, the interesting phenomenon of increased user searches for scientific content on social media (Hargittai et al., 2018). In this sense, it is precisely the disintermediation fostered by the Internet that allows for increased curiosity about researchers and research on the part of users, and the increased potential for direct interaction between the parties (Bucchi & Saracino, 2016).

As Liliana Gonçalves and Lìdia Oliveira (2021) pointed out in their systematic literature review on digital platforms, knowledge sharing and the flow of scientific relevance is informal and apomediate. Apomediation is a particular type of disintermediation which was defined by Gunther Eysenbach (2008) as an information-seeking strategy in which people rely less on experts and authorities, once considered "gatekeepers", and prefer to be "directed" by subjects that guide users to high-quality information and services albeit with limited individual power to modify or sift the information being exchanged. Therefore, apomediation consists of making use of intermediaries who facilitate access to accurate resources by directing searches in an effort to avoid unreliable and/or irrelevant sources.

In their study, Liliana Gonçalves and Lìdia Oliveira identify five knowledge sharing factors: social capital, network ties, perception, context, and individuals. In online participatory processes, communities, the interactions within and among them, the sense of belonging felt by individuals, personal expectations, and the perception of greater or lesser trust all seem to play a fundamental role. Equally relevant is the range of stakeholders that belong to three major categories: promoters/producers (government or local/national authorities or scientists), mediators (journalists, filmmakers, YouTubers) and the public (individuals, communities).

Promoters/producers are primarily involved in collaborative-based projects, mediators in citizen science projects. The third category, the public, is the main focus of this study. The public is the category that enables the sharing of knowledge between different groups, ideally the research world and non-experts. Our study analyses the public contribution offered in connection to the films *Don't Look Up* (2021), *Borat's American Lockdown* (2021), *Debunking Borat – Season 1* (2021), and *Barbascura X* and *Cartoni Morti's* YouTube channels videos about the climate crisis and the COVID-19 pandemic. These contributions represent samples of science-related content analyses that are multimodal in nature, including textual, visual and other elements that are systematically under-researched (Kessler & Schäfer, 2022).

In the peculiar context of the global pandemic, we believe that science experienced the same generalisation as politics (Beck, 1997). As a topic of attention shared by a multiplicity of actors and platforms (Scheufele, 2022), science has been attributed a higher agency than political actors, with consequent repercussions on the quality of the public discourse and trust in the health and democratic system. This process was particularly noteworthy in Italy (Belardinelli & Gili, 2020), evidenced by the 62% of Italians who in October 2020 believed that scientific experts gave too many different opinions (as compared to 48% in April 2020), and by the 26% of the population who were not sure about vaccinating or were totally against it (Observa, 2020). Within the already confusing regime of post-truth and the hybrid media system (Lorusso, 2018; Chadwick, 2013), the COVID-19 pandemic highlighted a deeper crisis: the critical nature of knowledge structuring as a process of coherent analysis and the decoding of reality (Doctorow, 2017). In deep mediatisation, the public sphere becomes fragmented and reconfigured into the individual truths of affective publics (Bentivegna & Boccia Artieri, 2021; Papacharissi, 2016), and this informational disorder was often combined with the pattern of marked hostility towards knowledge (Nichols, 2017). Indeed, common sense often reinforces confirmation bias and prevents understanding, and both reality as a negotiation between interpretations and social reality constituted by and through communicative processes becomes problematised (Shutz, 1971; Eco, 2006; Luhmann in Maddalena & Gili, 2017).

This paper aims to investigate whether and how irony can contribute to the reconstruction of information and knowledge as science has become more popularised. We believe that irony has the potential to merge the aesthetic instance of entertainment and the information provided by the platformed society (Maffesoli 1996; Mazzoleni & Sfardini 2009; van Dijck et al., 2019) as the narrative logic of post-truth requires episodic exaggerations of frames and privileges emotional processing (Lorusso, 2018; Fischer, 2021). As content, irony provides the perfect symbolic fabric to highlight sudden transformations in the binary oppositions that structure social life in the constellation of small-world-platforms (Vicari & Murru, 2020).

Science communication, irony, and humour: an overview of relevant studies

The range of studies that have experimentally investigated the potential of transmitting content (not only of a scientific nature) through humour and irony is varied but numerically limited. Among these studies, the critical contribution of Hauke Riesch (2015) highlighted the power of persuasion exerted by humour and the consequent need to employ it in science communication. In the increasingly complex digital public sphere, information regarding social and scientific issues is increasingly accessed through social media platforms such as Facebook (Brossard, 2013; Hargittai, 2018; Mueller-Herbst et al. 2020) and YouTube (Dubovi & Tabak, 2021). These platforms are structures that not only enable the production, distribution, and sharing of content, but also determine narrative styles. It is not insignificant that online engagement through humour has become prevalent, and therefore we need "to look closely at the interface between human being and technological mediation" (Weitz, 2017, p. 2).

It is crucial to consider the complexity of today's digital society in which the deficit model in scientific communication needs to be overcome by looking at persistent social inequalities (Scheufele, 2022). It would be possible to reformulate the very idea of post-truth into poly-truth, i.e. fierce public battles about truth by individual users (Harambam et al., 2022). In this way, we problematise knowledge construction crises related to communicative processes that are phases of construction and co-construction of reality, which is in turn a negotiation between interpretations and social reality. Over the last ten years, several studies have highlighted the cognitive and emotional potential of information collected online and the link between humorous entertainment and increased awareness, both regarding climate change and health. For example, stand-up comedy makes science more appealing and breaks stereotypes about scientists (Pinto et al., 2015), and humour has the potential to increase engagement in climate activism and social action (Yuan & Lu 2022). An important part of this process is that information that comes in a humorous message may initially be dismissed as a joke but remains in viewers' minds and therefore has the potential to influence their attitudes at a later time (Nabi et al., 2007). In this regard, it has been established that online scientific content arouses considerable interest, and that emotional and cognitive engagement with science on social media are interrelated (Dubovi & Tabak, 2021). Content that evokes emotional responses prompts users to comment more and thus to engage in a one-on-one exchange through which they share personal meanings about science with other users. In addition, humour appears to be positively related to users' perceived sympathy and trust toward the communicator (Looi & Ho, 2023), and gives a positive impression of the communicator's level of competence (Yeo et al., 2020). However, users' engagement with subtler forms of humour (Yeo et al., 2021), such as irony, remains largely unexplored.

Toward an operational-theoretical definition of irony as a vehicle of knowledge

Looking at studies of ironic humour in social media reinforces the idea that irony is a boundary work that, on the one hand, is able to consolidate group identity and, on the other hand, is able to exclude others who do not share the same symbolic frames, linguistic codes, and values (Gal, 2019). This view can be traced back to the three following established theories of humour: incongruity, superiority, and relief.

Briefly, the first theory concerns the sudden perception of incongruity between a concept and the real objects, and laughter represents the intuition of the coexistence of a sense of reality and its negation. The second theory indicates the social and cultural constraints that humanity imposes on itself (Watson, 2015) by assuming that what induces laughter is the possibility of asserting one's own superiority at the expense of others. The third theory explains how laughter is a reassuring emotional or psychic release valve connected to the saving of cognitive energy.

In order to arrive at a more precise definition of the object of our investigation, we first identify irony as a constitutive property of all contemporary practices of the imaginary (Chouliaraki, 2014, p. 175) and also as a post-narrative tool as it is not moralising and does not have universal intent. Arguably, it is both overused and misunderstood as a resource for exploring contradictions and uncertainties, especially in science communication. As Linda Hutcheon (1994) argues, irony corresponds to the intersectional dimensions that constitute a person's identity. Therefore, it does not build communities per se, but is based on the multiple and coexisting discursive communities that a person may know, belong to, and interact with. In this sense, it is linked to the concept of reflexivity, seen as universes of choices (Giddens, 1994) and interpretations. In our view, irony can bridge the hypothetical and contested distance between the expert and the users through a relational dynamic, according to which:

Ironic meaning comes into being as the consequence of a relationship, a dynamic, performative bringing together of different meaning-makers, but also of different meanings, first, in order to create something new (…) Irony isn't irony until it is interpreted as such – at least by the intending ironist, if not the intended receiver. Someone attributes irony; someone makes irony happen (Hutcheon, 1994, p. 4–11).

This contrasts with studies on ironic humour in digital environments, according to which irony is based on imitation and social affiliation (Gal et al., 2022). However, the relational dynamic has also been analysed as a performative dialectical function that can be understood and corresponded to (with a correct decoding of the message or not) in which case the relationship breaks down. In general, this rupture has been traced back to the elitist potential for irony, and tends toward reinforcing the boundaries between ingroup and outgroup. In an open and polysemantic digital context, there is a flourishing of forms in which irony can be expressed and explained (Dynel, 2017), and indeed attracts attention as it represents an overt clash of content (Garmendia, 2018, p. 123). The clash however only concerns the way in which content is presented, while the individual's possibility of approach pertains to the discursive communities they refer to and which are therefore multiple.

It is important to point out that a relationship between humour, irony, and sarcasm exists, as irony is a slippery concept, and though inked to the other two, has a tendency to assume a negative or controversial position and to shift meanings in unexpected ways. Irony, however obvious it may be, is not immediate but requires cognitive effort on the part of the receiver. Therefore, it can also be seen as an analytical tool (Watson, 2015), especially in the field of communication. But an analytical tool is nothing but a heuristic resource, like the frame. The most accepted definition of frames is: "organizing principles that are socially shared and persistent over time, that work symbolically to meaningfully structure the social world" (Reese, 2001, p. 11). Indeed, the authors believe that irony is a device very close to the frame in that it concerns tone before content and draws on shared cultural resonances (for a review see Bruno, 2014) and the potential of resignification in digital contexts (Vicari & Murru, 2020). This paper intends to answer the following research question:

RQ1: Can irony play a role in the construction and dissemination of information and scientific knowledge?

RQ2: If so, what kind of role does irony play, and through which forms, devices, and tools?

Research design

This study intends to test the following hypothesis: irony can be a tool for deconstructing the information disorder, and a rhetorical strategy for promoting awareness, merging the aesthetic instance of entertainment and information in the platform society with the emotional and episodic instance proper to the narrative logic of post-truth. The research design is structured on two levels of analysis. The top-down level concerns the analysis of twenty-four media products produced and published between 2020 and 2021 with an ironic/humorous slant that deal with the topic of knowledge science as applied to the COVID-19 pandemic, vaccination, and the climate crisis, and disseminated by leading streaming platforms such as Netflix Italy, Amazon Prime Video and YouTube (Starri, 2021). They include: Sasha Baron Cohen's mini-series *Borat American Lockdown* and *Debunking Borat*, the film *Don't Look Up*, and selected videos of *Barbascura X* and *Cartoni Morti*.

Despite their heterogeneity, the abovementioned content was selected because they are mainstream products in the international and Italian media (particularly the first two) and popular in terms of user-generated content capable of reaching and influencing many viewers. (The second two are among the most famous Italian YouTubers of popular content.) The target audiences of the four products are in fact randomly or non-homogeneously present (Greco, 2008; Brundidge, 2010; Zuiderveen Borgesius et al., 2016; Gal et al., 2022), whether on mainstream streaming platforms or social media platforms.

To consider the variety of the expression, presence, and effectiveness of irony across platforms, the present study, in keeping with its exploratory nature, adopted as broad and diverse a multi-platform perspective as possible. The bottom-up level focuses on the analysis of a random sample of 2,200 comments extracted by the free Export comments software from the posts or videos of content relaunches on Facebook, Twitter, Instagram, and YouTube from the official profiles of: Baron Cohen, Netflix Italy, and the YouTube channels of *Barbascura X* and *Cartoni Morti*.

The aims of our research are: 1) to identify the experimental narrative frames/strategies, and; 2) to classify and analyse users' reactions and comments, noting the degree of agreement/contrast and possible modes of resignification. Methodologically, the research relied on content analysis in previous studies (Berger, 1976; Berger, 1993; Hutcheon, 1994; Buijzen & Valkenburg, 2004; Juckel et al., 2016; Garmendia, 2018). The goal is to contribute to the theory of irony and humour studies as applied to digital science popularisation content. More specifically, we will consider the four categories identified by Berger (1976; 1993) for mechanisms of laughter: language, logic, identity, and action. This will be complemented by studies on television products (Buijzen & Valkenburg, 2004; Lieberman et al., 2009; Juckel et al., 2016). In addition, the social functions model of irony was applied to each content, which is defined by Hutcheon (1994) as follows:

Figure 1: The functions of irony (Hutcheon, 1994, p. 45)

The model proposes a non-hierarchical organisation of the functions historically recognised as irony in the field of semiotics. Thus, it represents a continuum, from bottom to top, of a more benevolent function in both tone and intention (reinforcing, complicating, ludic), a more critical intermediate zone (distancing, self-protective, provisional), and a more controversial zone in which irony becomes a strategy of provocation and polemic (oppositional, assailing, aggregative). The intensity of the affective charge involved in each level distinguishes the functions.

In the first level, the benevolent employment of irony has ambivalent implications. For instance, irony can be used to reinforce an argument, being perceived as emphatic or redundant. It can complicate communication, enriching the argument with ambiguities that can help clarify understanding or make it more tortuous. Finally, its ludic function may amuse or trivialise. In the second level, irony involves a distancing that also requires a greater affective charge on the part of the audience, either an opening of perspective or reduction to indifference. The self-protective function indicates the possibility of arrogant or strategic self-defence. The provisional function implies the ability to be changeable, thus demystifying or evasive. In the third level, the oppositional function expresses subversive or offensive contrast, the assailing function is directly satirical or destructive, and finally the aggregative function allows identification and membership or exclusion from discourse.

The further analysis of categories considers the presence of sources, tone of voice, visual elements (i.e. use of images, memes, emoji, collage), the types of structure of the narrative unit, the presence of testimonial, victim/target, and political criticism. We carried out a contextual qualitative-quantitative analysis of the comments considering the following: a) degree of agreement/understanding of the ironic content; b) presence of irony/humour devices; c) possible target of attack, and; d) manifested intentionality. The lexicometric analysis was integrated through R packages and the Iramuteq software, although the comment corpora are heterogeneous, cluster analysis returns the set of topics proposed by the users and consequently their proximity or remoteness from the content. This type of cross-analysis with qualitative analysis provides a deeper overview.

The coding phase was conducted by both authors separately, then discussed and shared, resolving ambiguities and excluding redundant categories. Adopting the Grounded theory approach (Strauss & Corbin, 1990, p. 9), we pursued the goal of building a theoretical explanation considering the action/interactions that give rise to phenomena and their consequences. The process of open coding was interpretive to break down data analytically and to investigate standard ways of thinking. Through a repeated comparison analysis, categories emerged "inductively from the corpus" on our two levels. We grouped the results into clusters, which can be traced back to the type of content and author, thus configuring four types of science dissemination linked to irony as a strategic resource.

Findings

Our analysis identifies four different narrative strategies of using irony: critical and civic activation, paroxysmal denunciation of the social system, satirical cartooning of the pandemic society, and pedagogical comedy.

The first strategy is provocative and assertive with the intention of inducing a reaction in the audience. It employs the grotesque, the awkwardness of surreal scenes, the use of specific objects, and rhetorical questions to emphasise the ironic message. Emphasis is never redundant but surreal to the point of complicating the content. This makes more evident the strategic use of irony as a signaller of the need to go beyond the commonplace. The critical capacity that is intended to be triggered is the possibility of a deeper understanding of the scientific content discussed in the media product. In fact, irony creates a distance that does not mock the protagonists or viewers but allows for a sense of temporary estrangement from the unfounded theory under discussion. The possibility of direct demystification (with an expert) or indirect demystification (by staging surreal assumptions) creates the margin of existence for doubt. This precedes understanding and becomes a tool for dissemination.

The second strategy is characterised by a paroxysmal denunciation of the social system. The use of parody combined with conceptual surprise overturns reality through the exaggeration of certain aspects. This additional form of meaning approaches the absurd and allows irony to manifest itself concretely in mockery, in the use of irreverent responses to serious statements, and in the exaltation of ignorance. Its specific functions are self-protective, defensive, and self-deprecating, able to simultaneously combine scientific content and popular counter-narratives. Irony makes it possible to equalise this clash of perspectives and make its paradoxicality evident; it is both provisional – evasive and non-dogmatic – and oppositional – subversive and offensive.

The third strategy is related to a cartoonised dimension involving the critical use of stereotypes, marked repetition of visual or verbal elements, and a strong presence of sarcasm. The functions of this strategic form of irony are assailing, and thus corrective and satirical, and also oppositional because it is transgressive in its choice of conveying content sagaciously and in an unfiltered manner. In addition, irony has an exclusive aggregative function in that it induces group recognition at the expense of the group of those who do not wish to understand or reason. The intent, however, is not mockery, but to highlight and deconstruct criticality and contradictions of controversial viewpoints.

The fourth strategy expresses the mainly playful and reinforcing function of irony using metaphors, hyperbole and exaggeration, puns, double meanings, rhetorical questions, and buffoonish attitude. Elements such as eccentricity, peculiar face or music or sound or voice, black humour, self-deprecation and transformations of known idioms are useful in the pedagogical construction of irony as an aggregative and inclusive function. Indeed, the possibility of embracing multiple formal and informal levels of meaning by explicitly but good-naturedly poking fun at popular beliefs about science makes it possible to make disclosure accessible and acceptable to all.

To illustrate each strategy in-depth, the communicators and the media products to which they correspond will be presented in detail below. A further and necessary operational premise is the assumption that irony manifests itself in conjunction with other mechanisms of laughter and is therefore not present in a strictly exclusive manner, especially in the context of the multimodality of digital environments.

It is already possible to trace the propensity for ironic irreverence with Sasha Baron Cohen on Amazon Prime video. In addition to the artistic elements of his work, the British comedian has always expressed a distinct political commitment and stance, especially during the presidency of Donald Trump. The pushback against disinformation and ideas spread by extreme right-wing populist circles materialised on a large scale first with *Borat 2*, and afterwards with the miniseries. The latter provides a close look at the comedian's experience of the 2020 COVID lockdown as the character Borat living at Jim and Jerry's house. The two men are the epitome of Donald Trump supporters. They are homophobic and suspicious of any source of information outside of the QAnon website. Jim and Jerry are convinced, for example, that Hillary Clinton drinks the blood of children, that the corona virus was created in a laboratory, that the vaccine is used by governments to control us by injecting a microchip under the skin. In *Borat 2*, the relationship of Jim and Jerry and the offbeat protagonist sets the stage for the strangeness of the three characters and the initiation of the docile and unsuspecting Borat into conspiracy theories.

The desire to demonstrate the paradoxicality of Jim and Jerry's (post-factual) truths accelerates over the course of the series. In the episodes, they openly confront, for example, an expert in the field of microbiology or virology, and finally even Hilary Clinton herself. The awareness of being filmed and publicly exposed by the two citizens is as much a marker of irony as it is of a willingness to respect people by talking to them. The two citizens do not become the laughing stock of the show but a key to interpreting today's reality, which necessarily includes other readings related to contentious issues. Here it is possible to discern the reinforcing function of the use of irony using both distancing and ambiguity. This is exemplified by a further marker (Figure 2), which appears at the beginning of each episode, but is also evidenced by the sense of explanatory estrangement present in the direct debunking exchanges between the professionals and Jim and Jerry. The use of stereotypes and the absurd represent the attempt to activate a media co-construction of reality, not at the expense, but with the contribution of "typical conspiracists".

Figure 2: Initial Debunking Borat disclaimer

Turning to Netflix's *Don't Look Up*, the film can be credited with being the first to openly recount the climate crisis and its effects. The narrative is developed around a potentially more concrete and immediately comprehensible emergency, the deadly impact of a comet against planet earth. Many critical aspects and strengths of the film have been highlighted within the scientific community. On the one hand, the film echoes the opposition between science, right-wing populism, and lay people aping established stereotypes. On the other hand, it also expresses the objective and dramatic consequences of global inaction in tackling the climate crisis.

Now we take up the open question of the social efficacy of this representation (Little, 2022, see the contributions in the special monograph issue of *JCOM*), and explore the efficacy of what we have called the paroxysmal denunciation of the social model. The film employs the non-dogmatic and self-protective irony of individual characters. For instance, the irreverent doctoral student is frightened and irritated by the senselessness of the President of the United States and the media system. Resorting to a reversal of reality, this is characterised by the public as parody, grotesque, satire. The film makes use of the paradox with the technique of estrangement and aggression, announcing it with explicit markers. An example of this is provided Figure 3, in which the reference is to a payphone service aimed at providing peace of mind to the public, despite the certainty of the end of the world, in the name of a greater good: the supply of resources (in this case the minerals that compose the comet) are being exploited for the capitalist ends of the multi-billion-dollar private tech company called Bash.

Figure 3: Advertising the emergency service in *Don't Look Up*

Turning to our next example, *Cartoni Morti*'s YouTube channel provides a satirical cartooning of the pandemic society. Social functions of irony here are aggregative and subversive and are employed to criticise and also to encourage awareness. Each animated format proposes a didactic narrative drawing on multiple, often official sources (i.e. WHO, the Ministry of Health, scientific journals), with tone and gestures tailored to the characters.

The channel creators express political and social criticism with an explicitly cynical sarcasm, using parody of stereotypes, repetition, and a complex proposal of absurdity. An effective example of this strategy is the evocation of Mussolini's Fascist dictatorship in a medical and vaccination context in order to highlight the contradiction of the arguments concerning the Italian health dictatorship during the lockdown from March to May 2020. Mimicking the typical gestures of the populist minister Salvini, the central caricature of Mussolini is as reasonable and open to dialogue as Prime Minister Conte. A monologue to a packed and jubilant square culminates with the rephrasing of the famous Fascist motto "Win and we will win!" with "The watchword is heal and we will heal!" (3:24).

The last case is the pedagogical comedy *Barbascura X*. The content creator is himself a researcher with a PhD in organic chemistry. The innovative modality he proposes is the dissemination of "ugly science" on YouTube. All published scientific content is scrupulously researched, openly drawing on the cultural resources of both the researcher and the character *Barbascura X* has created for himself: a pirate of the unexplored and untamed land of science.

The mechanism of laughter merge in a didactic cultural mash-up whereby irony is reinforcing and demystifying, always supported by more than one source. Distinctive features are the use of swear words, fictitious characters, and the transformation of facts into memetic media culture. Emphasis is placed on informal/familiar tones, aimed at reaching as wide an audience as possible and being understood. This aim is also pursued in the constant explanatory commentary, accentuated in particular by the post-production work of the video, which is rich with transitions and sound, voice and visual effects.

In terms of comments, the heterogeneity of the social media platforms analysed make it possible to identify differences in the way audiences interact. The relaunch posts, published by Sasha Baron Cohen and Netflix Italia, show a high level of communication and exchange among users. Instagram and Facebook posts addressed both creators, while Twitter was only used by Sasha Baron Cohen. Although pertaining to different content – basically a cross-media form of irony in the posts (i.e. re-releasing excerpts of the film or miniseries, making hilarious meme jokes, and emphasising the need to question what one thinks one knows) – the first two social media platforms render a coherent understanding of the mechanisms of irony. The cognitive effort involved in decoding irony seems to be present in that there is an openness to confrontation. We found a plurality of levels of interpretation. A recurring object of debate in the comments where there was both poly-truth of opinions and a search for dialogue was the possible space for scientific truth.

The expression of the plurality of levels of interpretation restores the rhetorical effectiveness of irony, which can trigger collective circuits of reflection. In addition, the length and visibility of comments on Facebook and Instagram allow for conversations that are not necessarily polarised between heterogeneous audiences.

Although mediated by the platform, an exchange between users is an example of public conversations on the subject not necessarily directed toward the content producer or director, especially in the case of Netflix where it is not possible for users to link to a particular subject and there is less fandom than just a community of subscribers. What is significant is the explicit manifestation of reflection in the form of a conversation regarding the meaning attributed to a media product. The irreverence and reversal of reality becomes the subject of discussion and not just of approval or disapproval.

The case of Twitter differs because elements of moralisation and polarisation are strongly present (for example, in defence of conspiracy theorists and anti-Semites). There is an evident and ambivalent hostility against "Rednecks", "Trumpists", and Hillary Clinton (called the "US government vampire"). Thus, on Twitter, irony becomes the pretext to vent social controversies and take sides in defence or in favour not only of the content but of its creator in both the American and international public spheres. Baron Cohen, as a celebrity who has exposed himself as a person, receives both direct endorsements – both on Twitter and Instagram – and political and anti-Semitic attacks, thus covering the distance from comedy idol to "dirty Jew".

The emergence of this individuality can also be seen in the case of the two YouTubers, *Cartoni Morti* and *Barbascura X* analysed in this paper. Although these only concern the Italian public, the discussion engaged in by users related to these videos reveals how the possibility of direct interaction with the creator allows users to become more active, asking questions, and requesting specific explanations. Users do not seem to be a community of followers, rather individual followers and disparate users who are reached by the popularity of the content, and take time to comment on it. Irony, therefore, does not seem to constitute an elitist boundary beyond which knowledge is placed, rather it becomes the expression of possible cognitive and collective entertainment. It is not only a stylistic feature of the creators' innovation, partly dictated by the engagement standards of the platform, but the key to transferring attractive and apparently simple understanding and knowledge. Users express open appreciation and esteem for the content (Figure 4 in red) and the creator (Figure 5 in light blue), both being considered shareable, ingenious, and effective in terms of style and message.

However, irony also represents a challenge that emerges from the presence of conceptual polarising dynamics. When the irony becomes more pungent, it is possible to detect fractures in its interpretation (Figure 4 in purple and green; Figure 5 in purple and red). Some users tend to adopt the ironic style, others reject the "unspoken" content that con-

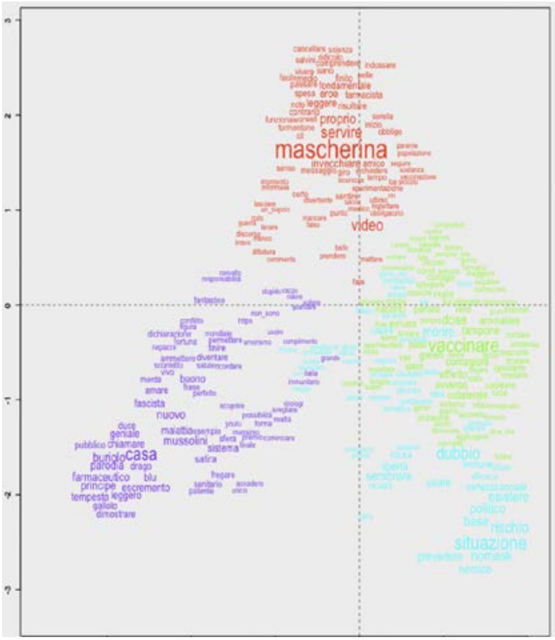

Figure 4: Cluster analysis of Cartoni Morti's comments

tradicts their own beliefs about vaccines, the health system, and social norms. This refusal can be traced back to the specific belonging of users to different "discursive communities", usually communities that are far from the origins of the proposed scientific content and defensive about confrontation. To the extent that irony is rejected and/or not understood, it seems to challenge belonging. And yet, in its non-clarity, it opens a small space for understanding the true meaning of the content. In fact, even just the expression of disapproval or the request for explanation via comment engages the user in a public conversation related to each video. This commentary serves to question what users interpreted through the cognitive filter of belonging, albeit in a limited and mediated way.

A further aspect concerns the dimension of doubt. As can be seen in Figures 4 and 5, it seems to mingle – especially as regards vaccines – with the positions of the detractors (in green and light blue in Figure 4; in red and green in Figure 5). Anyone can express a position of doubt

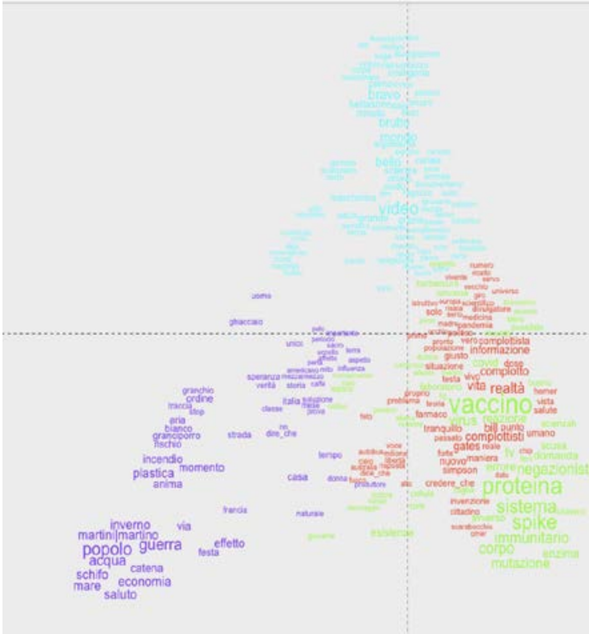

Figure 5: Cluster analysis of Barbascura X's comments

about the specific content and the way in which it is conveyed. Therefore, the irony of the media content can activate doubt in the user and this possibility creates the space to weaken or strengthen individual beliefs. It all depends on the quality of the exchange generated by sharing doubts and participating in the discussion in the comments section. The potential of doubt should be further investigated in order to gain a greater understanding of how much space it grants to the construction of collective knowledge.

Conclusion

In view of the findings presented in this paper, it is possible to conceive of irony as an applicative and revealing lens of inconsistencies in reality, and a gateway to understanding existing universes of meaning including those of the users. We believe that irony can constitute a dynamic practice of heterogeneous digital communities, of provocation and suggestion, which changes as social, cultural, historical, and media references change. Since each individual belongs to several "discursive communities" (Hutcheon, 1994), irony and its markers concerning scientific communication on social media platforms can be considered a framework of personal references that combines from time to time with the network with which it is confronted. Those who post and write comments position themselves as active participants (Dubovi & Tabak, 2021) and trigger a process that create dialogical spaces of confrontation, open to the sharing of experiences and thoughts on science and the co-construction of knowledge by users.

Universes of meaning (Giddens, 1994) that individuals draw on also collide with the clash over content that irony represents (Garmendia, 2018). The complexity of ironic communication lies precisely in the composition of the following elements: the role of intention and attribution, and its contextual framing and markers. As noted by Linda Hutcheon (1994), the possibility of recognising irony lies in individuals' membership in multiple communities with a range of beliefs, ideologies, and unspoken notions, which are not limited to social status and gender, but concern what orbits the individuals' life universe on a daily basis. In this sense, the permeability of science popularisation is made possible by irony in a hybrid media context involving one-to-one exchanges.

The mechanisms of irony are structured as a discursive strategy that, like frames, places knowledge in a certain form. Frames can be seen as a kind of kaleidoscopic response to poly-truth by the content creators and producers analysed in the present study. Moreover, they are able to express social change and provocation by co-constructing knowledge.

One of the possible risks of irony concerns the perception of derision and exclusion which, for example, assailing and oppositional irony can arouse. However, the responsibility for the ambivalence with which irony is sometimes interpreted lies as much in the intention of the author of the content as in the confirmation biases of those who perceive themselves as being attacked either as a member of an out-group or a public minority (i.e. the case of the anti-vaxxers during COVID-19 pandemic). Irony is not a tool that makes comprehension impossible, but an analytical instrument that works on the transmission of content by requiring the effort of attention. Nevertheless, it leaves room for interpretation and thus doubt and hopefully discussion and the co-construction of knowledge. Its rhetorical and non-exclusive effectiveness lies in its dialogical potential.

In the post-truth era, especially in digital environments, irony can draw out the critical dimension of an unexpressed need for social trust in a cohesive and unique interpretation of reality and scientific truths. This limit returns the problematic nature of a digital sphere composed of the complexity of individual users. Given the exploratory nature of this initial research, we believe further studies could include semi-structured interviews with both creators of content and their audiences regarding engagement and discursive intentionality. Furthermore, in order to define a meaningful pattern of dissemination in digital contexts, it would be important to map other experiences of expertise using irony, particularly as the evidence of its actual and potential use by institutional actors on social media platforms grows (i.e. Instagram and TikTok).

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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.

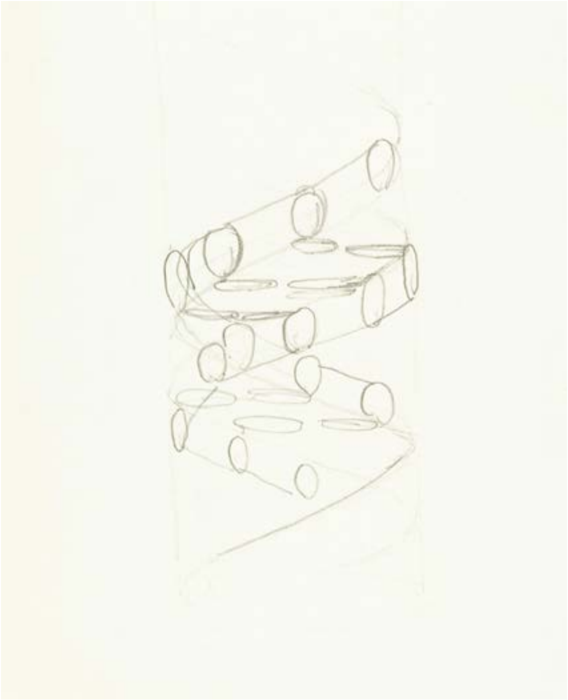

Figure 1: Pencil sketch of the DNA double helix by Francis Crick, showing a right-handed helix and the nucleotides of the two anti-parallel strands. Wellcome Collection. Attribution 4.0 International (CC BY 4.0), retrieved from https://wellcomecollection.org/works/kmebmktz

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.

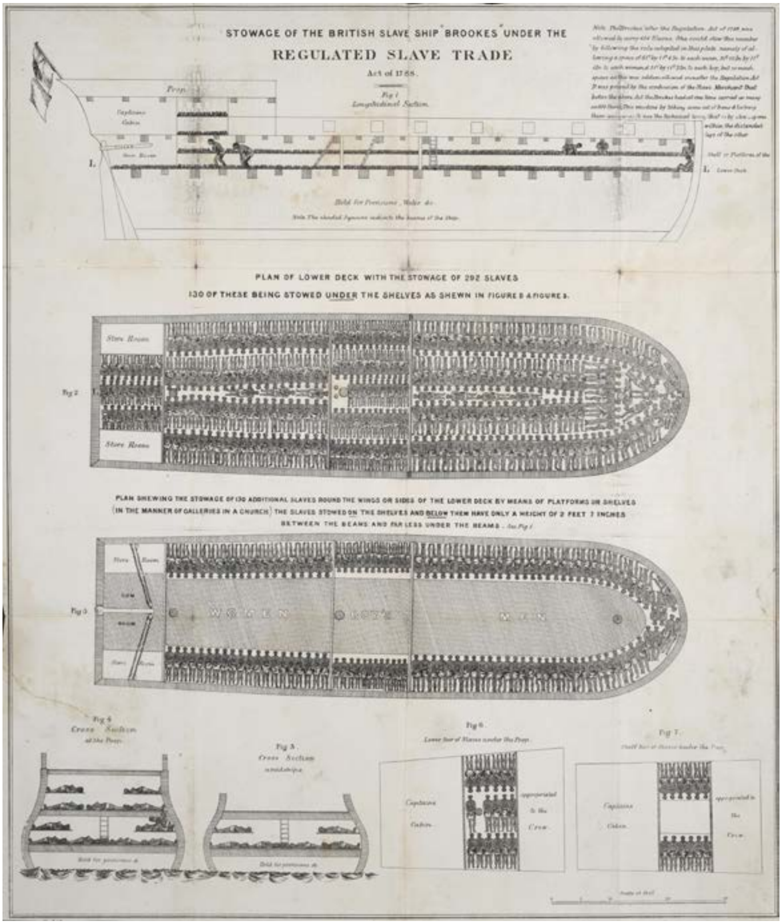

Figure 2: Stowage of the British slave ship Brookes under the regulated Slave Trade Act of 1788, retrieved from https://commons.wikimedia.org/wiki/Library_of_Congress

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.

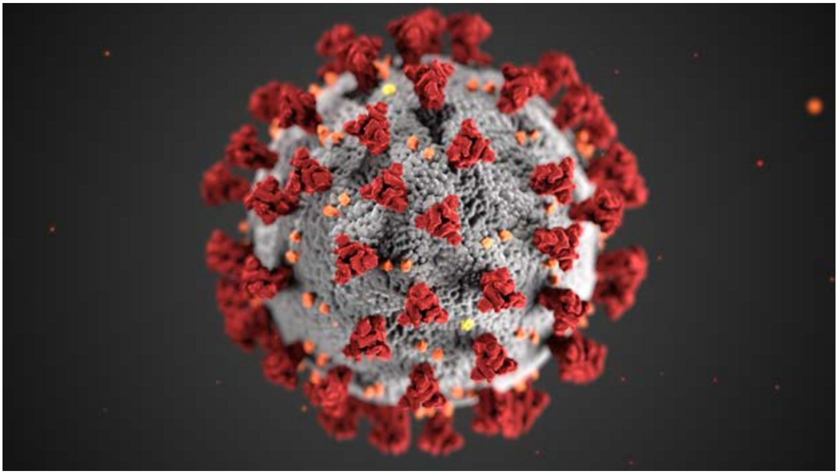

Figure 3: SARS-CoV-2, Alissa Eckert, MSMI; Dan Higgins, MAMS, Centers for Disease Control and Prevention (CDC), retrieved from https://phil.cdc.gov/Details.aspx?pid=23311

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.

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Cecilia Lartigue and Aquiles Negrete

Watering the Lava Flow: The Use of Comics in Communicating Scientific Information about Water Conservation

Introduction

Water scarcity is one of the main concerns in Mexico City (Dominguez, 2006). About one-quarter of its inhabitants do not receive enough drinking water in their homes to satisfy their basic needs. Fifteen percent of the population do not receive water on a daily basis and nearly two million depend on water trucks (EFE, 2021). The prospect for increasing water resources is virtually non-existent as there is a serious hydric imbalance in Mexico City: water is extracted at more than double the rate than what is recharged into local aquifers and about one-third of the water supply is lost to leaks (Breña Pujol y Breña Naranjo, 2009).

The main campus of the National University of Mexico is located in the south of Mexico City and occupies nearly 740 hectares. About eighty-eight litres of water per second are extracted from local wells for different uses, one of which is the irrigation of one hundred hectares of gardens. A total of twenty-two litres per second are used for this purpose (PUMAGUA, 2013), and this water is used in an inefficient way (PUMAGUA, 2012).

Most of the areas of the campus currently planted with grass were originally covered by a xerophytic and thornshrub ecosystem (Figure 1) with an outstanding biodiversity and landscape value (Lot & Camarena, 2009). As a matter of fact, scattered along the campus there are still about forty hectares of this original vegetation (Zambrano et al., 2019). This kind of vegetation has many environmental advantages, such as no need for irrigation and little maintenance requirements (Lot & Camarena, 2009).

We decided to disseminate water saving irrigation practices, including both grass watering and substitution of grass with native vegetation, as part of a water management program within the university. In connection with this project, we created a narrative that included relevant information to be addressed to the university community in general. Our justification for doing this was a widespread lack of awareness about these matters that was established previous informal surveys carried out by UNAM's students.

The suitability of using art-based methods in sustainability research has been widely discussed by Heinrichs and Kagan (2019) as a way of "grasp-ing with novel methods the corporal-sensorial affective dimensions of human action in routinized socio-material practices, and allow[ing] for new imaginative processes". These authors emphasise the importance of art in mobilising emotions, intuitions, the subconscious, and tacit knowing. Art-based methods also allow research into the area between the known and the unknown, while respecting ambiguity. Similarly, in their article about communication of ecological information through artistic expressions, Curtis et al. (2012) point out how art promotes new ways of regarding ecological issues, how it touches emotions, and can even create a festive mood.

Narratives, as a form of art, can be defined as "a particular structure that describes the cause-and-effect relationships between events that take place over a particular period that impact particular characters" (Dahlstrom, 2014). The aim of narratives is to explain a series of causally linked events that unfold over time (Norris et al., 2005). They are a useful tool to represent and communicate knowledge for the following reasons among others: people are familiar with the narrative format of communication (Negrete, 2009; Yang & Hobbs, 2020), and narratives are an effective emotional detonator, a long-term mnemonic structure, and an important reinforcement for learning (Negrete, 2020; Negrete, 2021)

Comic strips (the longer forms known as graphic novels) are a form of narrative with a proven success in science education and communication (Tatalovic, 2009). This is because text and illustrations presented together work well to improve learning (Hosler & Boomer, 2011) as they induce the use of several parts of the brain (McCloud, 1993). They are also a form of narrative enjoyed by a significant part of the population. Since 2009, over 950 million comic book units have been sold globally, which account for 13.5% of total book sales during this period (Curcic, 2023).

Mexico is a country with poor reading habits. In 2021, about 70% of the literate population read "something" (books, magazines, newspapers, or internet page) (Varela, 2021). Less than 40% read a book during the year prior to the survey, the majority of whom were people with at least secondary school education (Instituto Nacional de Estadística y Geografía, 2022). Furthermore, the main reason for reading is enter-

Figure 1: Vegetation of the Ecological Reserve of El Pedregal de San Angel, UNAM (source Reserva Ecológica del Pedregal de San Angel)

tainment. For instance, in 2002, nearly twenty million entertainment magazines, including comic strips, were sold in Mexico (Chavez Mendez, 2005). The fact that comic strips appeal to a broad sector of the Mexican population makes them a very promising medium for environmental communication.

Many studies have been undertaken about the impact of narrative communication, including one by Golding et al. (1992), who carried out an experiment in order to test the hypothesis that individuals respond better to risk communication via narratives than technical information. Likewise, Negrete and Lartigue (2004) measured the effectiveness of learning tasks when scientific information is included in a short story compared with when it is conveyed through a traditional factual text. Betsch et al. (2013) compared the effect of narrative and statistical information about vaccine-adverse events on vaccination decision, and Yang and Hobbs (2020) compared the effectiveness of using factual texts versus narrative information to communicate with consumers about a new biotechnology application. All of these studies found that narratives were more effective than factual/technical information.

In contrast, very few studies address the effectiveness of comics to convey scientific information (Farinella, 2018). For instance, Hosler and Boomer (2011) found that an improvement in attitudes about biology was correlated to attitudes about comics, suggesting that this type of narrative may have contributed to shaping student attitudes in a positive way. In a similar study, Weitkamp and Burnet, (2007) created a comic strip that was presented to primary school students. The authors of this study found out that students were able to give scientific explanations based on the information provided in the comic strip. Lin et al. (2015) compared the effectiveness of a comic book and a text booklet about nanotechnology. They discovered that both instruments were effective in terms of conveying information and improving attitudes towards the subject. However, the comic book increased pupils' interest and enjoyment of learning while the opposite happened with the text booklet.

Literature about the impact of comics in environmental communication and education is scarce. Richter et al. (2015) conducted one such study in which the authors used comic strips to convey information to primary school students about nature conservation and sustainable development. They discovered a significant positive effect of this narrative on knowledge acquisition.

Hands et al. (2018) investigated the influence of an educational comic strip on the future gardening intentions of urban residents. Although the authors discovered that the narrative had a positive effect on future plant choice of respondents, they also found that the response was not generalised. Therefore, they conclude that comics should be used in conjunction with other instruments.

Regarding the use of comics to encourage water conservation, Houben (2019) created a comic strip about the importance of groundwater addressed to Paraguayan primary school students. Although he was not able to quantitatively measure the impact of the illustrated narrative on children's knowledge and attitudes, teachers that presented the comic strip to their students received interesting feedback which led to the following interesting recommendations: 1) Use positive characters with which children can identify. 2) Use negative characters to personify environmental problems. 3) Do not forget fun and suspense. 4) Use landscapes, buildings, plants, and animals of the country or region in which you are working. This will enhance identification with the story. 5) A happy ending is necessary, such that the problems presented are brought to a successful conclusion, which is best achieved through the actions of the main characters themselves.

This paper presents our findings in the construction and evaluation of a comic strip about water saving gardening practices. In this first exploratory stage of the project, the comic strip was presented to a sample of UNAM's students. In terms of literary genre, we chose to write a detective story because this genre captures the reader's attention through an intriguing plotline. As Baps (2020) states: "It is a combination of curiosity into the darker side of humanity that influences our general interest into crimes and murder mysteries. Our brains want to connect pieces together to solve the puzzle innately."

In order to assess the effectiveness of our comic strip in conveying environmental information, we used the RIRC method (Negrete & Lartigue, 2010). Specifically, this method was designed to assess the retention and comprehension of information by using four independent memory tasks: recall, identify, retell, and contextualise (the acronym corresponding to the first letter of each task). The input of the RIRC method consists of a qualitative complex stimulus, such as a narrative or another text format and the outcome is measured through a questionnaire.

Method

Identifying the information to be communicated

As part of the activities of the water management program, we carried out several workshops, in which forty-five gardeners from the main campus of UNAM participated. The aim of these workshops was to learn about their gardening practices, specifically their irrigation methods and their perceptions of native vegetation. Among other things, we found that there were no clear criteria for deciding how much water to use in the different areas of the campus. In addition, we learned that although they expressed a positive opinion about native plants, only half of them were interested in replacing the grass with this kind of vegetation. Consequently, we decided to include the following two key issues in the comic strip:

A simple method for knowing when plants are overwatered is to take a handful of soil, and, if it immediately breaks down, it means that the soil is overwatered.

Important benefits of native vegetation of the campus include that it survives on rain water and has low maintenance requirements.

Creation of the comic book (Appendix I)

In the abovementioned workshops, gardeners frequently mentioned that they perceived a lack of respect for their work from the community. People constantly walked through the areas where they worked, damaging the grass, while also demanding that the grass be green all year round. We concluded that it would be worthwhile to make their work visible, while also communicating information about gardening water saving practices.

Under our supervision, several students participating in the water management program were tasked with creating the story and making the drawings. To make the comic appealing to the audience, we decided to write a detective story. These kinds of texts, at least in their Mexican variants, tend to include some amount of violence, a practice to which we yielded but only to a modest degree.

To highlight the environmental information we wanted to convey, we attempted to present a simple conflict, a straightforward resolution, and include only a few characters. Also, we decided to leave a third of the images without text to give the reader breathing space, and when texts were present, we kept them short. Likewise, we tried to make sure that the images were attractive but did not overshadow the text. In this way, we hoped to enhance the reader's interest in the story.

Due to the fact that we opted for a detective story, which, as mentioned above, typically includes some violence, and that it took place in the main campus of UNAM, where lots of people walk from one place to another, we thought it was important not to alarm the readers. Therefore, we introduced characters far from reality, in particular, the burglar and the detective. We believed that this would establish a certain distance between the audience and the story.

In contrast, due to our interest in making the gardeners' work visible, we opted to depict them as cooperative, proud of their job, and knowledgeable. In this sense, the information that we actually wanted to disseminate was already known by the gardeners of our story. The bad practice of some of the gardeners that is frequently detected by the community of UNAM (e.g. irrigating for long periods or placing sprinklers in the wrong places) were pointed out in the comic as something alien to them.

The following is a summary of the story. While walking by the gardens of UNAM's main campus, a young girl's purse is stolen by a mysterious man. The girl is in shock and cannot give a statement. The police call a detective who carries out an in-situ investigation. He visits the crime scene, and asks a gardener if he has seen anyone suspicious. The gardener answers that he has indeed witnessed suspicious activity, by which he means that the gardens are being excessively watered, something that is unusual in their working area. Consequently, he is sure that someone not in the crew is pretending to be a gardener. The detective visits other areas in which there is native vegetation and the gardeners tell him the advantages of these kinds of plants. Finally, they set up a trap for the burglar, which leads to his capture.

Evaluation of the understanding and retention of environmental information

We carried out a survey in one of the main green areas of the campus, an area visited by people from several schools nearby. Through a random sampling, we approached individuals and selected those who were students of UNAM. Those that voluntarily agreed to participate in our study were asked to read the comic strip and then answer a written questionnaire with eight questions (Appendix II), two for each task, according to the specifications of the RIRC method.

Both explicit and implicit memory were evaluated. Explicit memory was measured through three basic tasks: declarative knowledge, recognition, and recall. Implicit memory was assessed through procedural knowledge. Table 1 shows the description of each task, as well as the type of question used for this purpose.

Table 1: Tasks for measuring implicit and explicit memory

Task	Description	Type of question
Explicit memory		
Identify	Select or otherwise identify an item as being one that you learned previously.	Multiple choice
Recall	Produce a fact, a word, or other item from memory.	Fill in the blank
Retell	Repeat the items on a list in any order in which you can retell them.	Open-ended question
Implicit memory		
Contextualize	Remember learned skills and automatic behaviours rather than facts.	Open-ended question

First, we carried out a pilot survey in which seventy-eight questionnaires were used in order to assess the reliability, or internal consistency of the instrument. We measured the Cronbach alpha coefficient and found that our questionnaire had good reliability ($\alpha = 0.83$). Therefore, we used 195 more questionnaires, bringing us to a total of 273.

Results and discussion

Our main findings are summarized in Table 2 and Figure 2. As they both show, in terms of the percentage of correct answers, the comic strip proved to be an effective means of communicating information about water conservation practices. Although there is room for improvement, the average of correct answers for the eight questions is a passing grade (64%). It should also be noted that performance was particularly high for two questions (1 and 5), while performance for questions 3 and 6 tended to be low.

Table 2: Percentage of correct answers for the different memory tasks

Question	Correct or partially correct answers (%)	Incorrect answers (%)
Identify		
1. When a handful of soil breaks down easily, it can be due to…	89	11
2. What do grass and native plants of El Pedregal need to survive?	62	38
Retell		
3. Overwatering is not a good idea for…	44	56
4. What are the benefits of having native plants of El Pedregal in our campus?	87	13
Recall		
5. For how long should the gardens of our campus be watered?	58	42
6. What happens if they are watered for longer periods?	46	54
Contextualise		
7. If you lived in a city where water is scarce and your house had a big garden, which actions of the Impostor presented in the comic book would you carry out in order to decrease water consumption in irrigation?	65	35
8. How would you know if you were using too much water in irrigation?	58	42

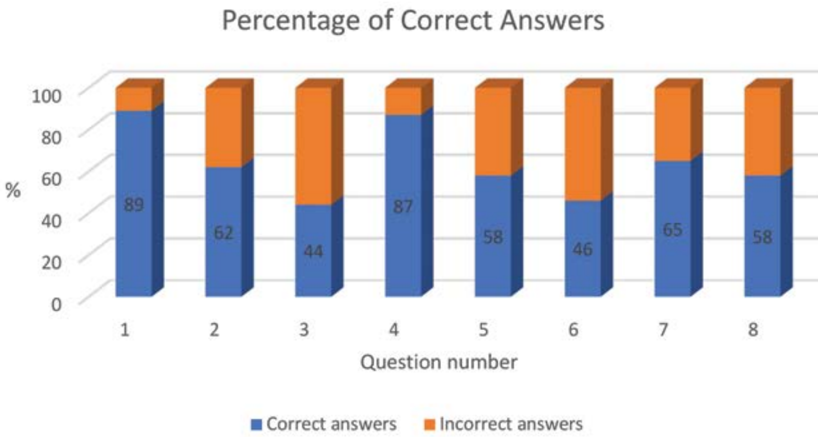

Figure 2: Percentage of correct answers for all the questions

As Table 2 and Figure 2 show, most of the answers were correct or partially correct (at least one or two correct answers were provided for questions with several correct answers). However, there were also two questions (a *retell* and a *recall* one) in which the number of incorrect answers was higher than the number of correct ones. Perhaps this was due to the fact that those two questions were not specific enough or perhaps even ambiguous ("What happens if plants are watered for longer periods?", and "Overwatering is not a good idea for ___"). Likewise, the average percentage of correct answers for the whole questionnaire was 64, which corresponds to a passing grade, but leaves plenty of room for improvement.

It is worth pointing out that the two questions with the highest number of correct answers ("When a handful of soil breaks down easily, it can be due to ___", and "For how long should gardens of our campus be watered?") were those with only one possible correct answer. Participants had a better performance in these questions than in those that had several possible correct answers, even when we considered it correct when only one was provided.

It is interesting to note that the participants' performance did not correspond to the degree of complexity of each memory task. In other words, *identify* did not show a better performance than *recall*, or *re-*

call than *retell*, and so forth. Apparently, performance is related to the kind of questions presented and perhaps to other aspects, such as the place within the comic book where the information is located. For instance, the answer of one of the questions with a good performance is located almost at the beginning of the comic book. It is one of the first scientific facts provided, while another scientific fact that was frequently remembered was placed at the end of the comic strip.

Likewise, the two questions with the highest performance referred to information that was accompanied by images in the comic book. This finding is backed by the study of Houts et al. (2006) in which it was determined that images closely linked to text can, when compared to text alone, significantly increase attention and recall of health education information. In future studies, it would be interesting to test whether these two factors (location within the narrative and linking of images and texts) are indeed determinant for participants' performance.

One of the main challenges in the creation of *The Impostor* was to write a story that captured the readers' attention. Therefore, a significant part of its beginning consists only of the plot of the detective story. Nevertheless, it was also our aim to provide a considerable number of scientific facts, as well as information to enhance the image of gardeners. In addition, we needed to keep the narrative short in order to avoid losing the readers' interest. All of these requirements may have resulted in an excessive concentration of scientific information in the middle part of the story. In future projects, it would be worthwhile trying to distribute this information throughout the comic book in a more balanced way.

It is worth mentioning that many of the characteristics of our comic strip were derived from recommendations made by Houben (2019): specifically, the use of suspense; the presence of positive characters that the reader may identify with (environmentally responsible gardeners), and of negative characters to represent bad environmental practices (the thief); the depiction of landscapes with which readers are familiar (different places on the main campus of UNAM), and; a happy ending achieved by the actions of the characters (in the end, the thief is caught by the detective).

In the near future, we would like to test *The Impostor* using a sample of gardeners as well as with other members of the university community, such as lecturers, researcher, and university authorities, in order to compare our results with those of this study.

Looked at from a wider perspective, this paper contributes to art-based research. As Heinrichs and Kagan (2019) point out, although the importance of paradigmatic methods of communication have been recognised, environmental challenges "are overwhelmingly approached in sustainability science through normative, discursive, textualist, mentalist ways, and through an excessive narrowing-down of possibilities in the solutions-orientation." Our work might contribute to emphasising the enhancement of sensorial experience, cognitive evaluation, and imagination provided by artistic works, which would encourage engagement on sustainable development. Furthermore, the plot of *The Impostor* could be represented through other media, such as an audiobook or a video. It would be interesting to assess the impact of alternative sensory experiences on the effectiveness of science information communication.

Conclusions

As a whole, we believe that the comic strip *The Impostor* represents an interesting and successful communication material that could help to enhance better irrigation practices and to encourage more respectful attitudes towards native vegetation conservation as well as gardeners' everyday labour.

This work reveals interesting facts, such as the importance of where scientific information is placed within the comic strip, the need for spreading the information out in order to enable the reader to process the information acquired, and reinforcing the idea that images are helpful aids for memory performance. But undoubtedly, the use of narratives and other artistic works has the potential to encourage responsible water practices.

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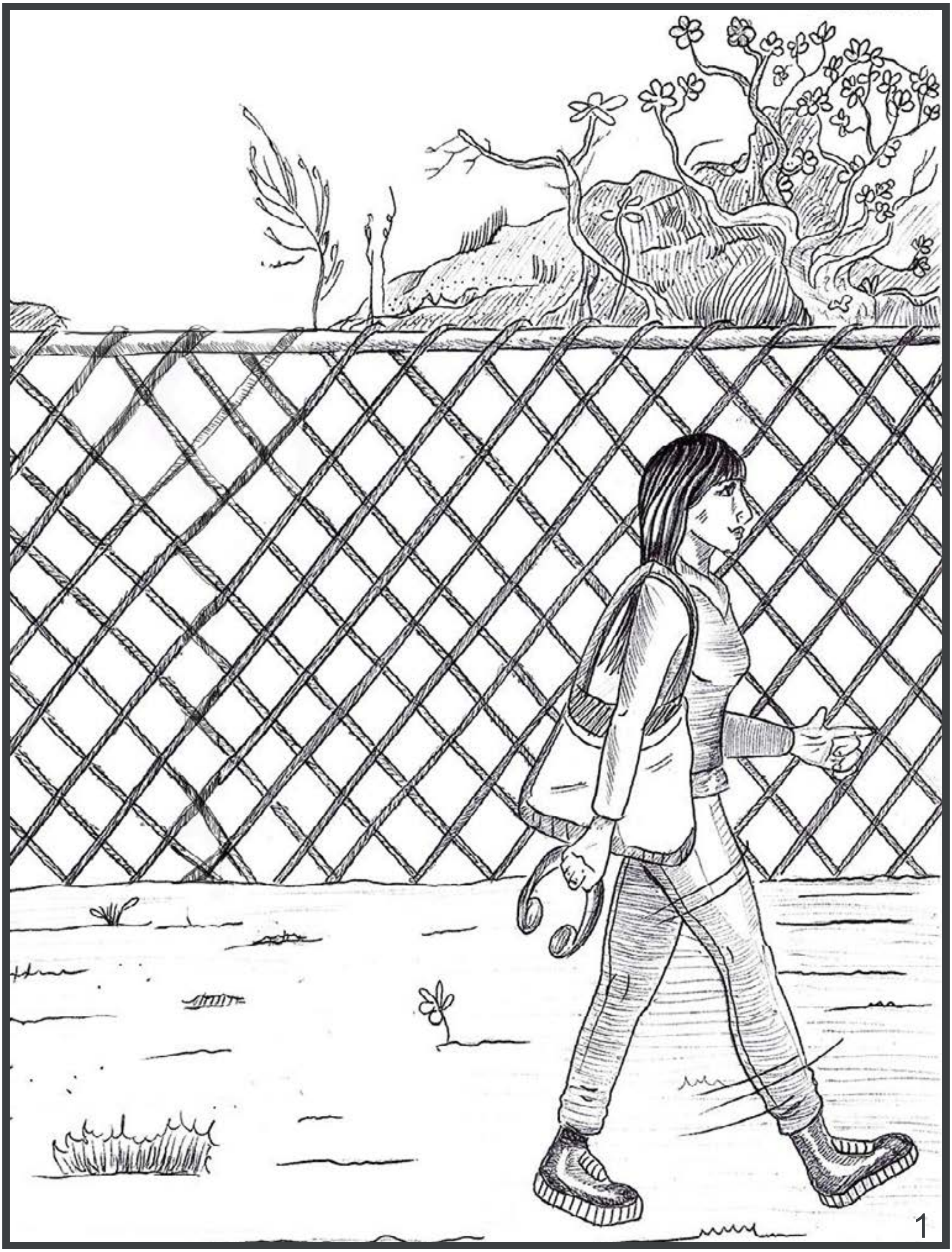
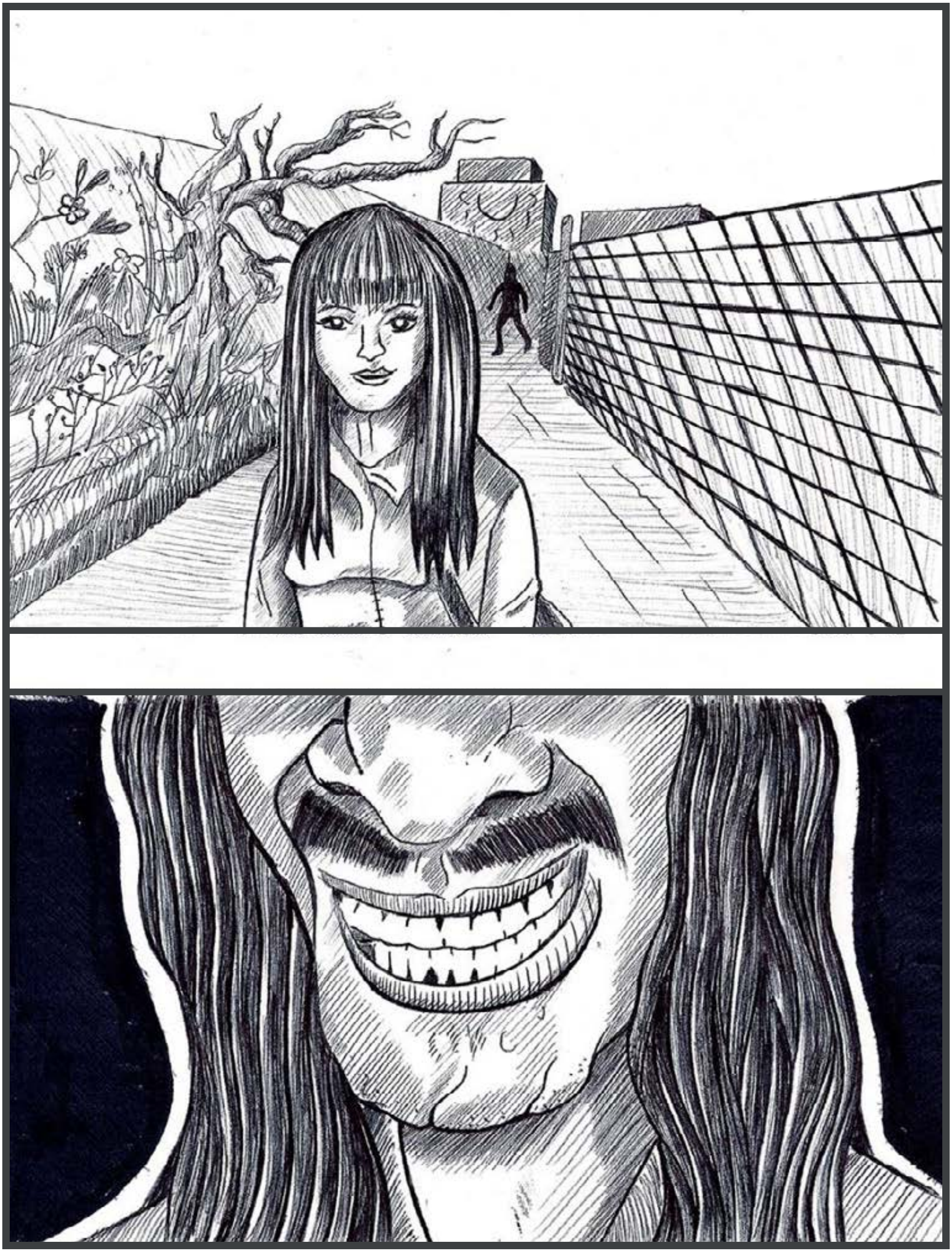
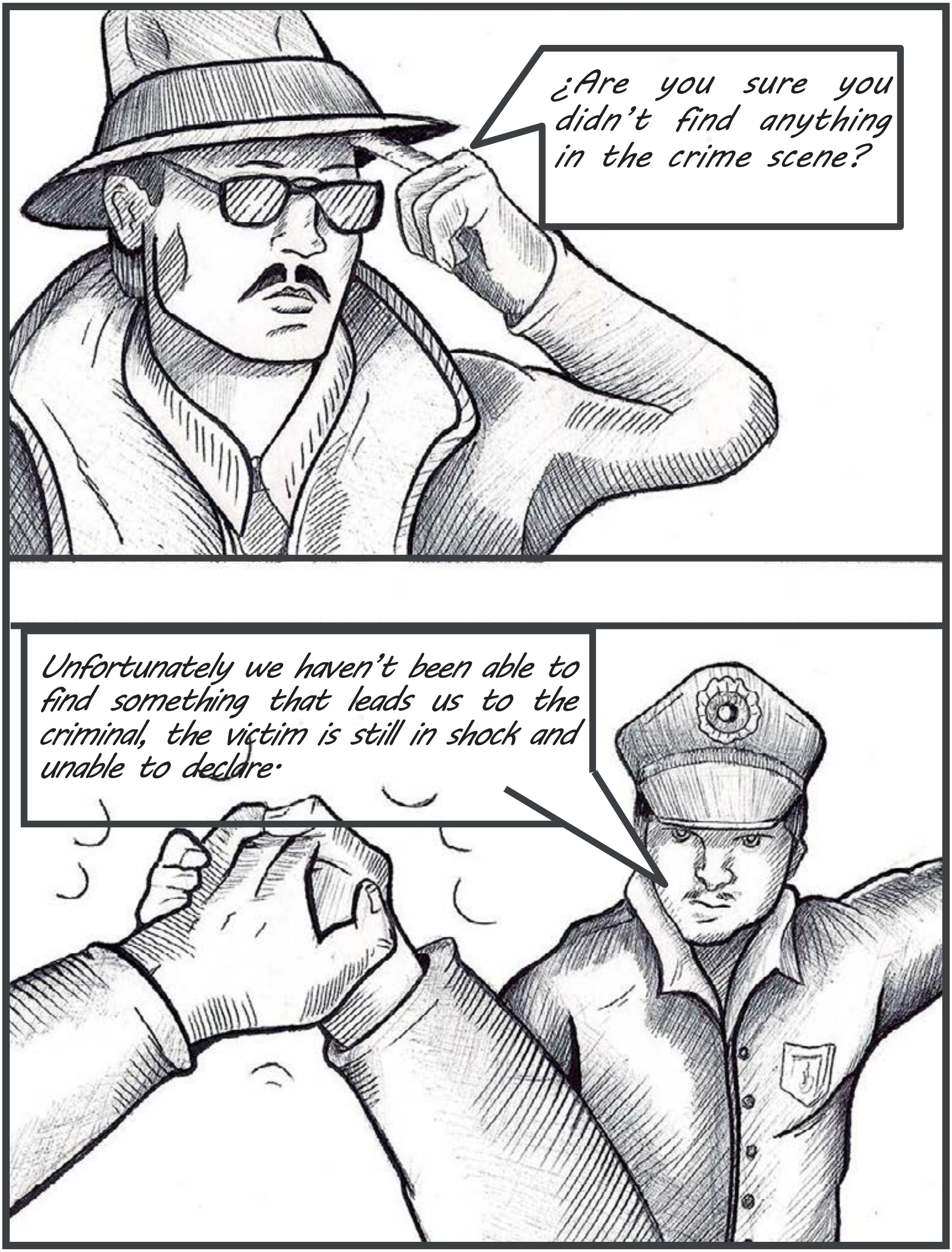
Appendix I

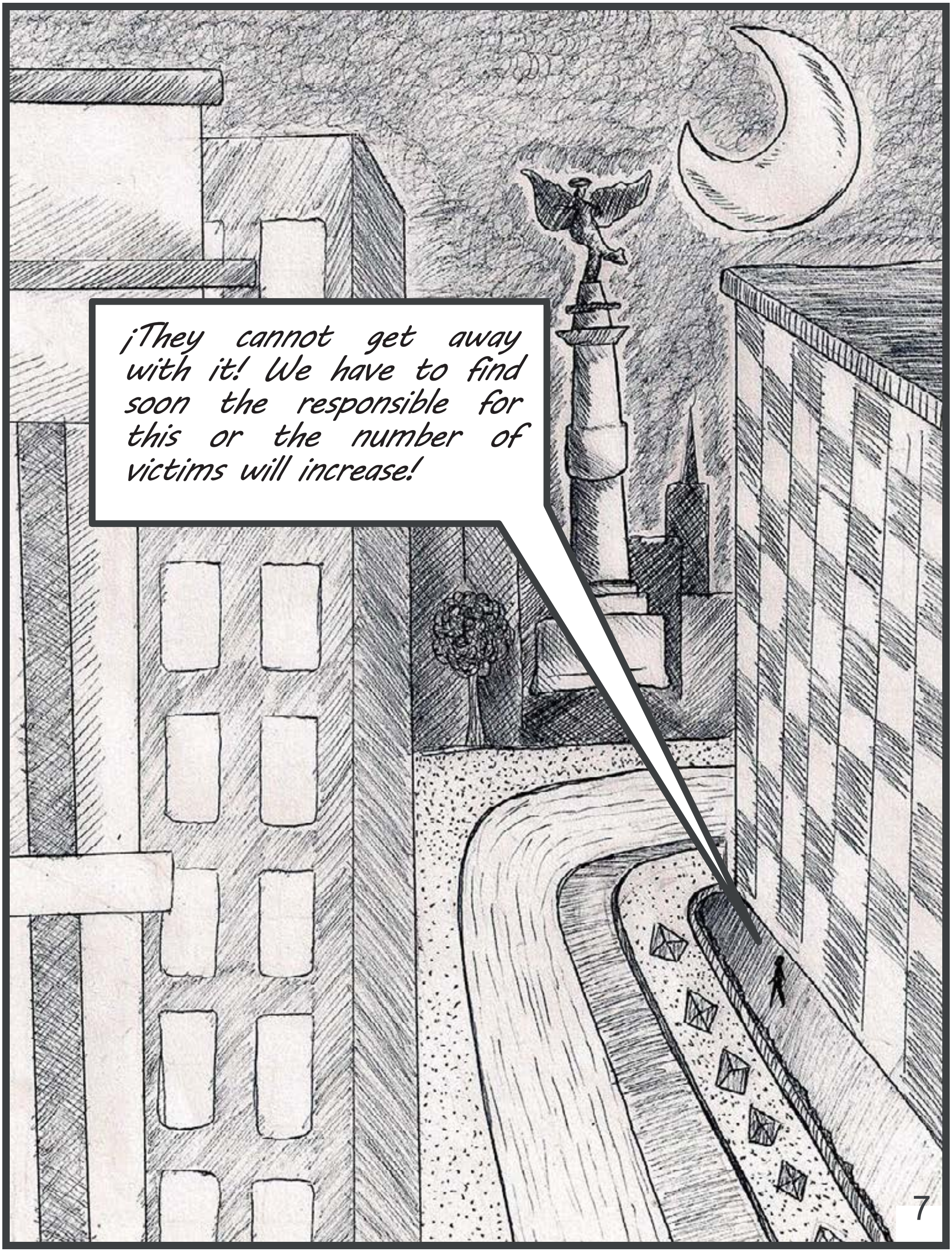
The impostor

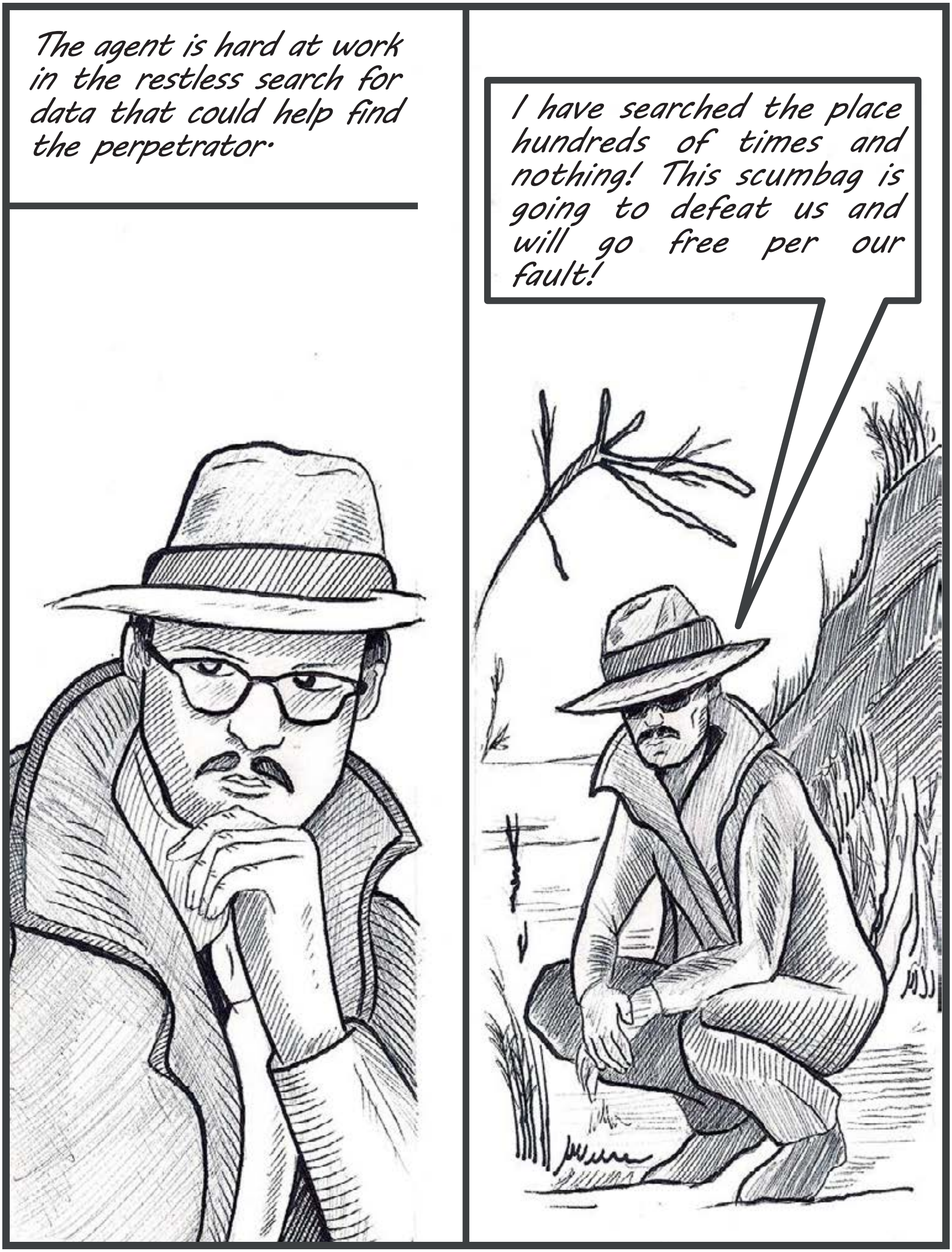

1

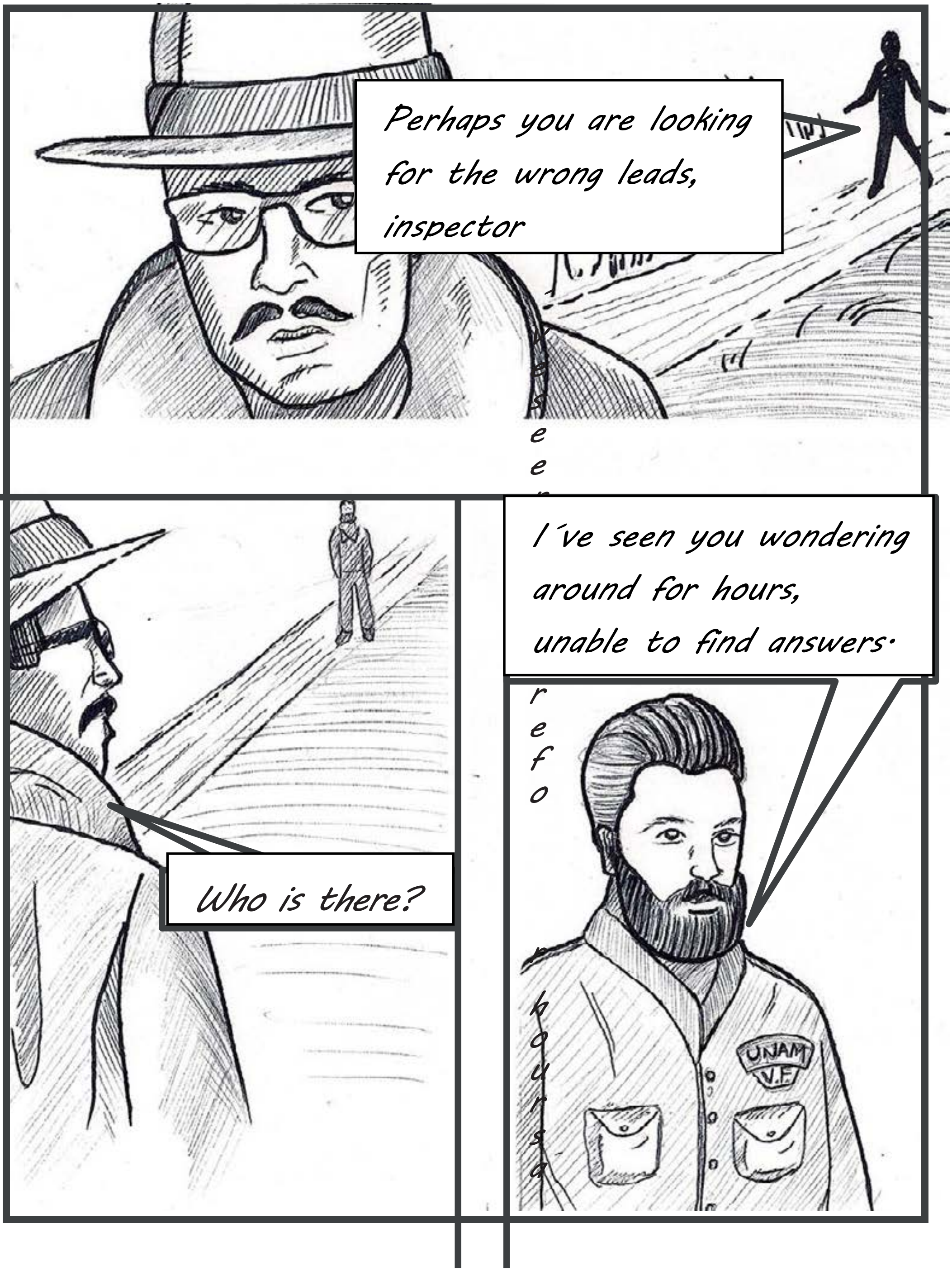



Police Headquarters...
Since the beginning of this year, 6 thefts have happened, two of them this month. The burglar has speed his process...
5


¿Are you sure you didn't find anything in the crime scene?
Unfortunately we haven't been able to find something that leads us to the criminal, the victim is still in shock and unable to declare.

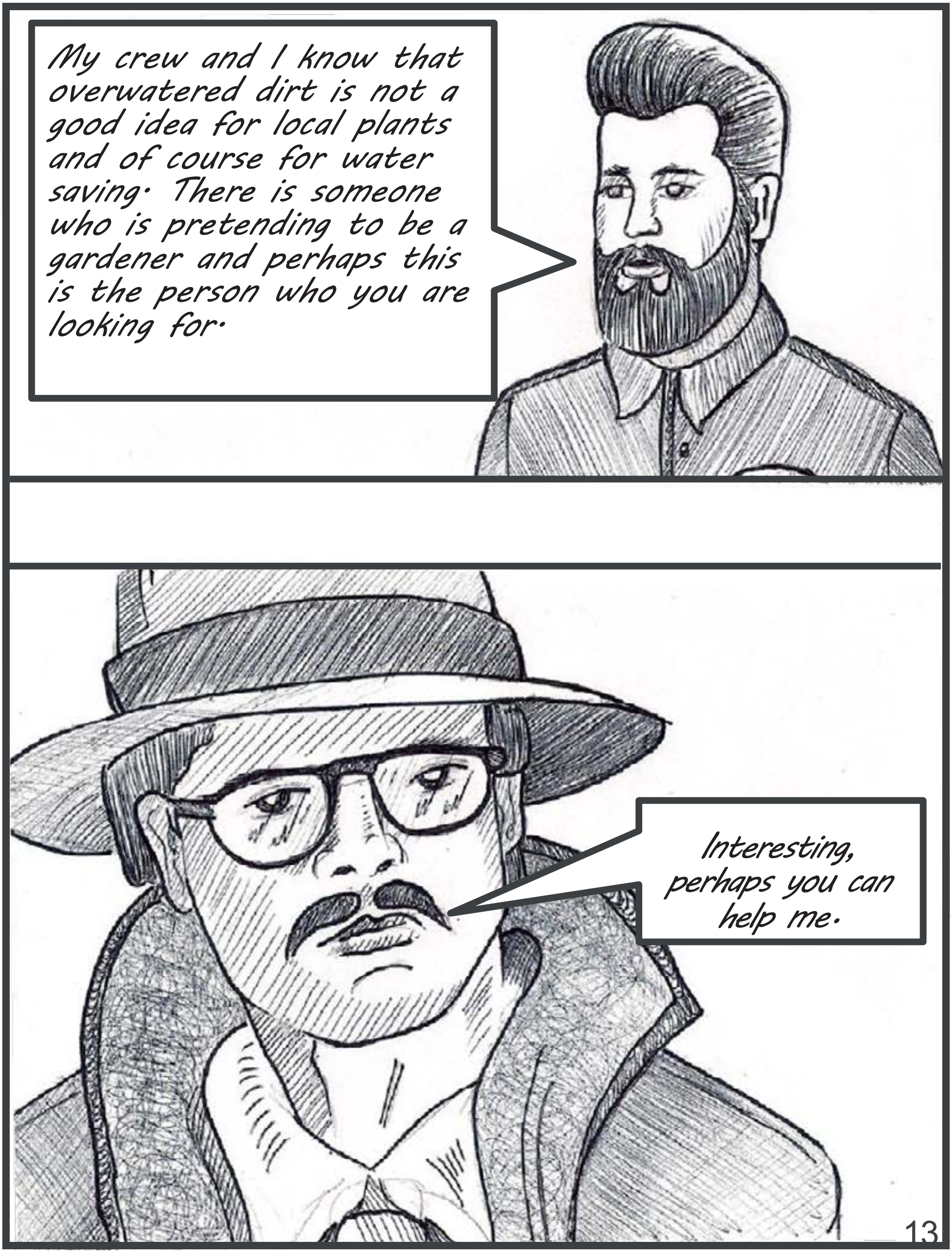

¡They cannot get away with it! We have to find soon the responsible for this or the number of victims will increase!
7

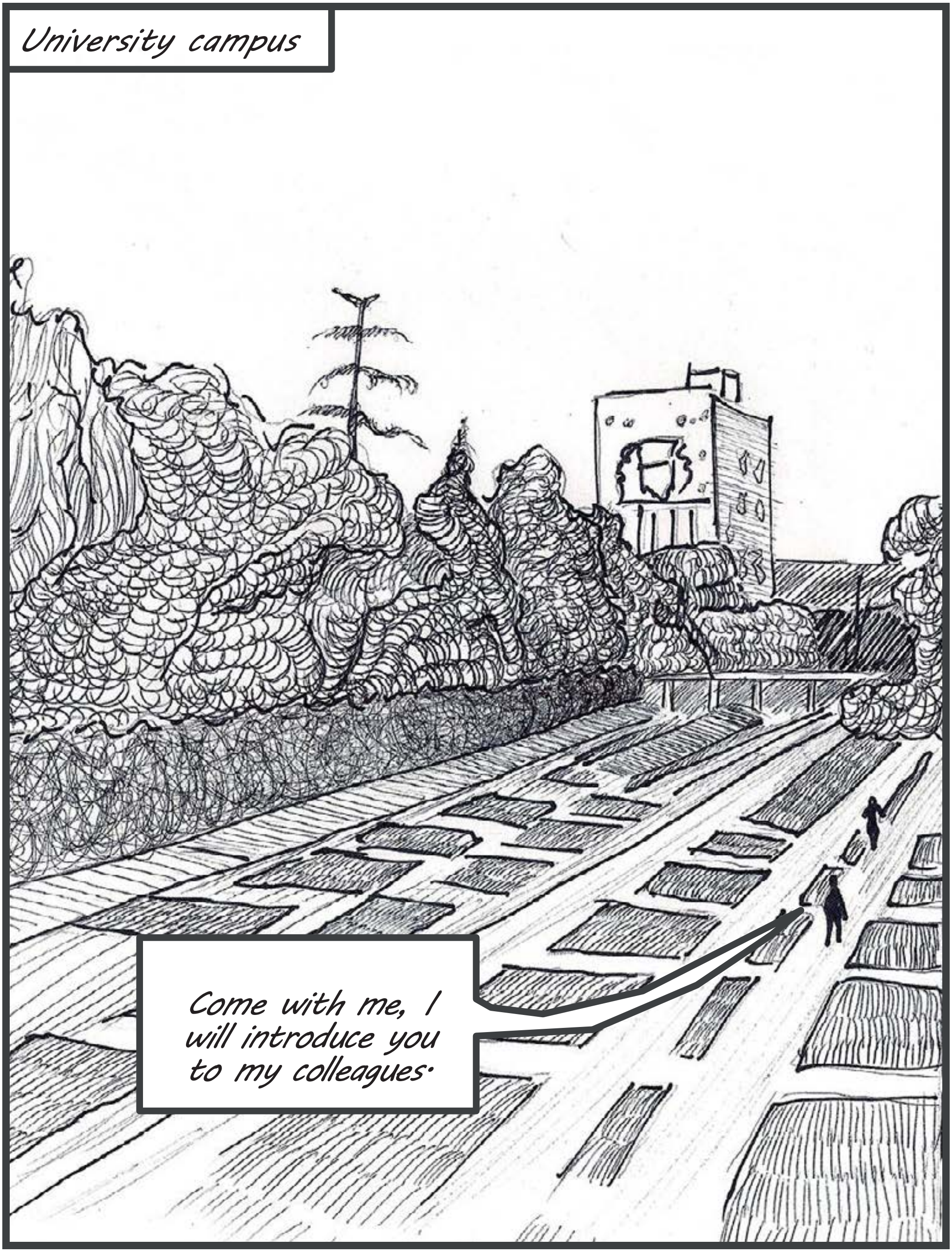

The agent is hard at work in the restless search for data that could help find the perpetrator.
I have searched the place hundreds of times and nothing! This scumbag is going to defeat us and will go free per our fault!


Perhaps you are looking for the wrong leads, inspector
Who is there?
I´ve seen you wondering around for hours, unable to find answers.


And that do I have to listen to???
I am one of the gardeners working here, I know this land and its plants like my hand.
It is obvious that lately something is wrong here.
UNAM V.F
UNAM V.F
11

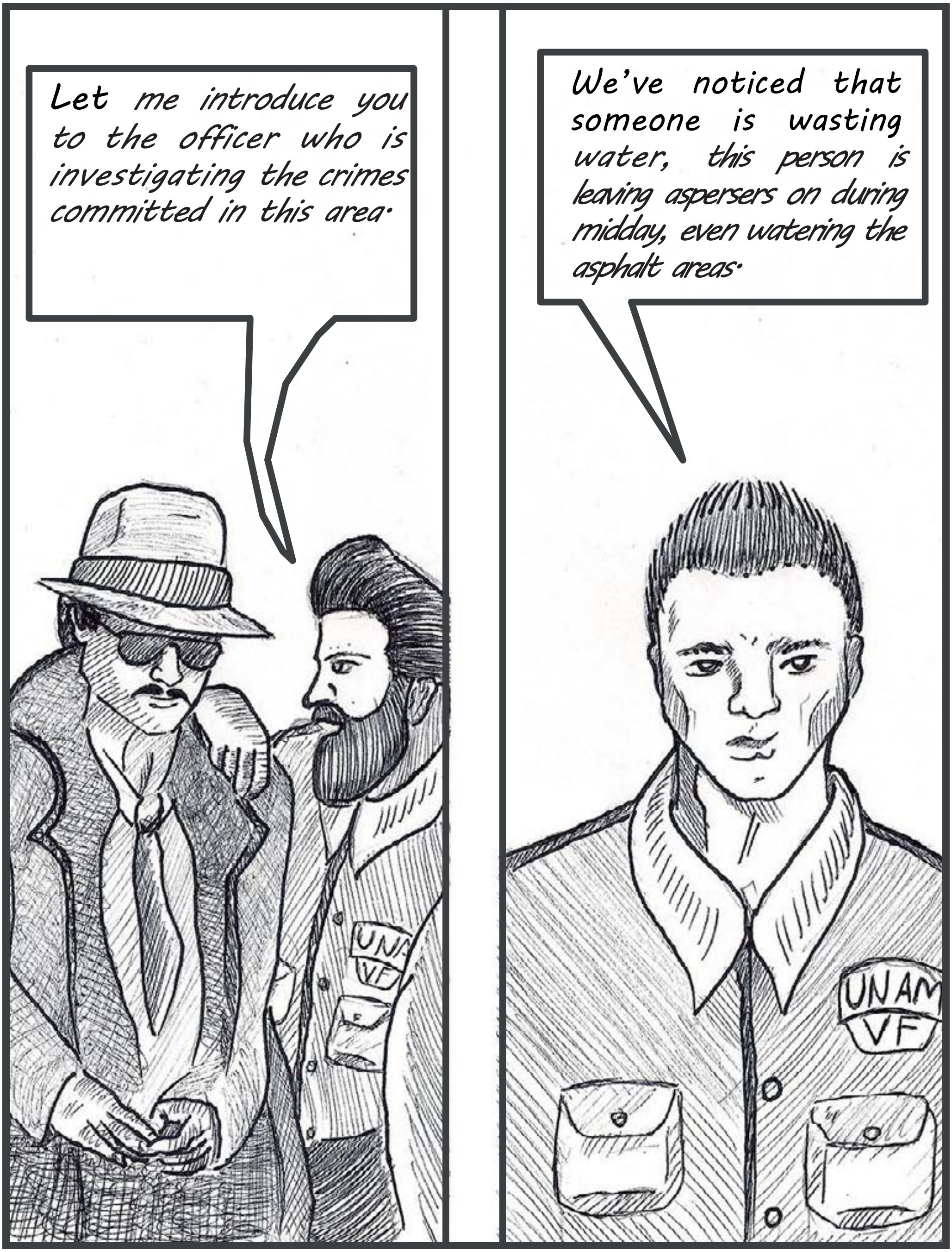

¿What is that supposed to mean?
The gardener takes a handful of dirt in his hand, shaking it and letting it crumble.
Look, the dirt disintegrates very fast, meaning that it's saturated in water.

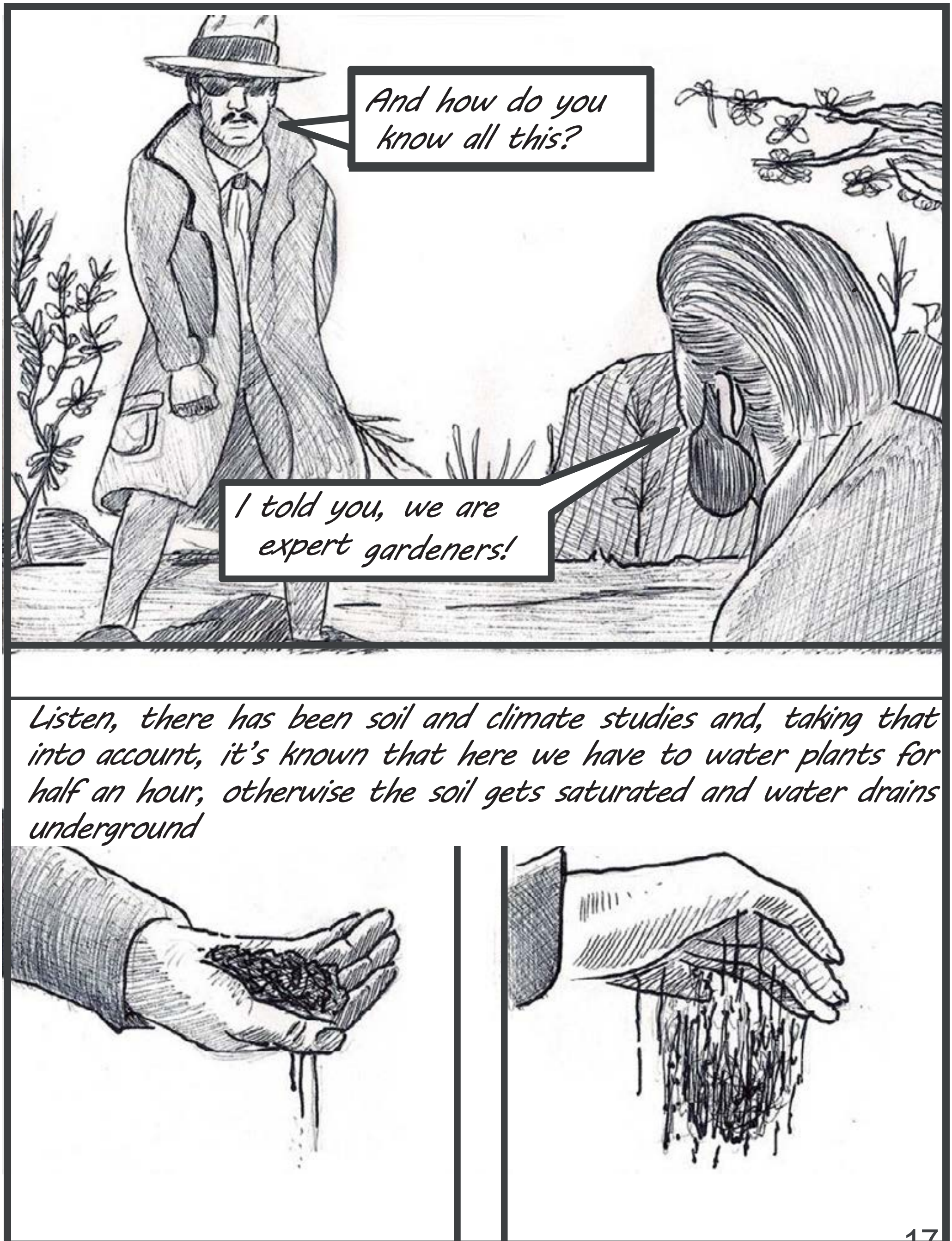

My crew and I know that overwatered dirt is not a good idea for local plants and of course for water saving. There is someone who is pretending to be a gardener and perhaps this is the person who you are looking for.
Interesting, perhaps you can help me.
13

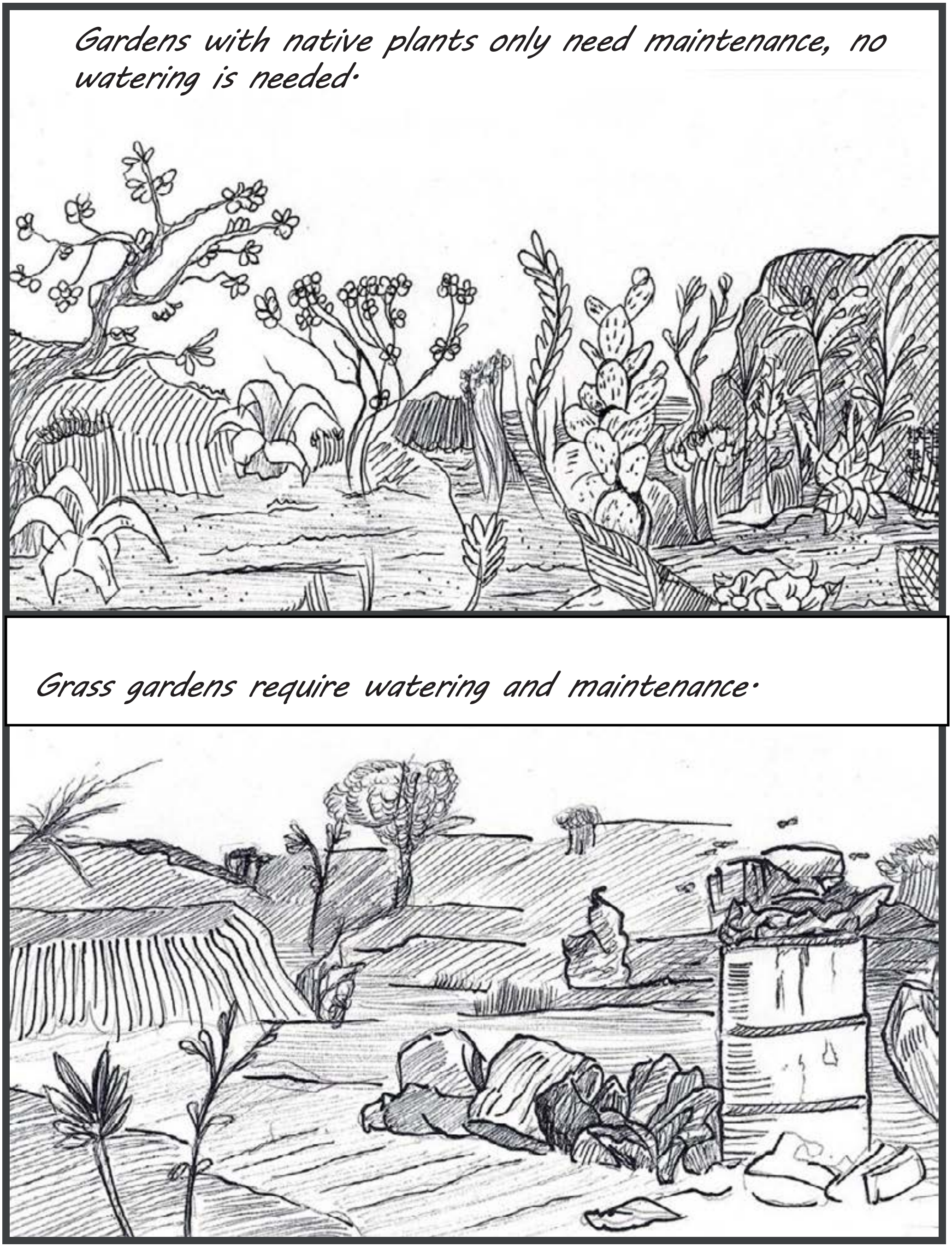

University campus
Come with me, I will introduce you to my colleagues.


Hello, what's up fellows?


We are planting native species from the Pedregal to preserve the ecosystem and reduce the need for watering. The rainwater should be sufficient for the plants to grow and flower all year long..
15

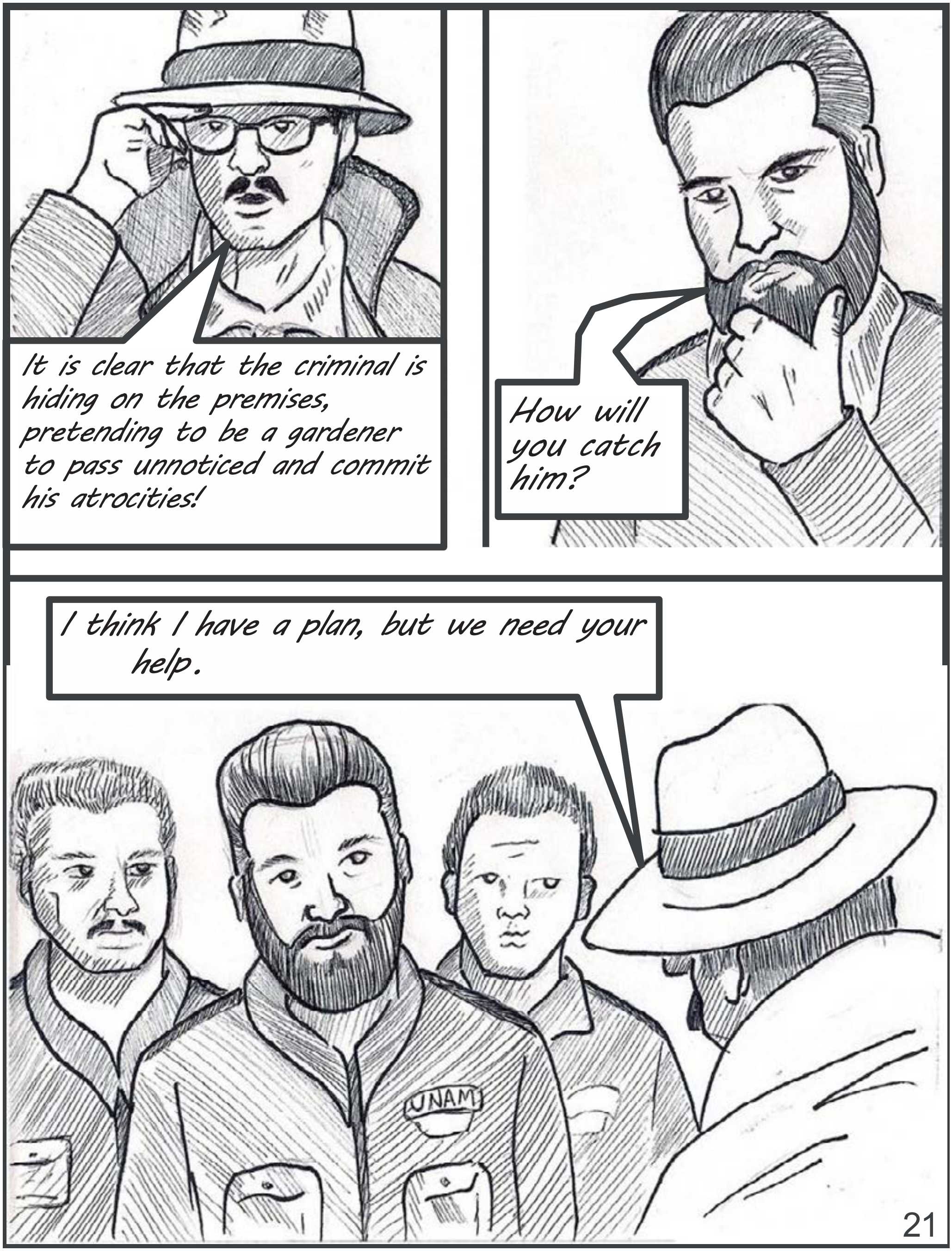

Let me introduce you to the officer who is investigating the crimes committed in this area.
We've noticed that someone is wasting water, this person is leaving aspersers on during midday, even watering the asphalt areas.
UNA VF
UNAM VF


And how do you know all this?
I told you, we are expert gardeners!
Listen, there has been soil and climate studies and, taking that into account, it's known that here we have to water plants for half an hour, otherwise the soil gets saturated and water drains underground
17


Gardens with native plants only need maintenance, no watering is needed.
Grass gardens require watering and maintenance.

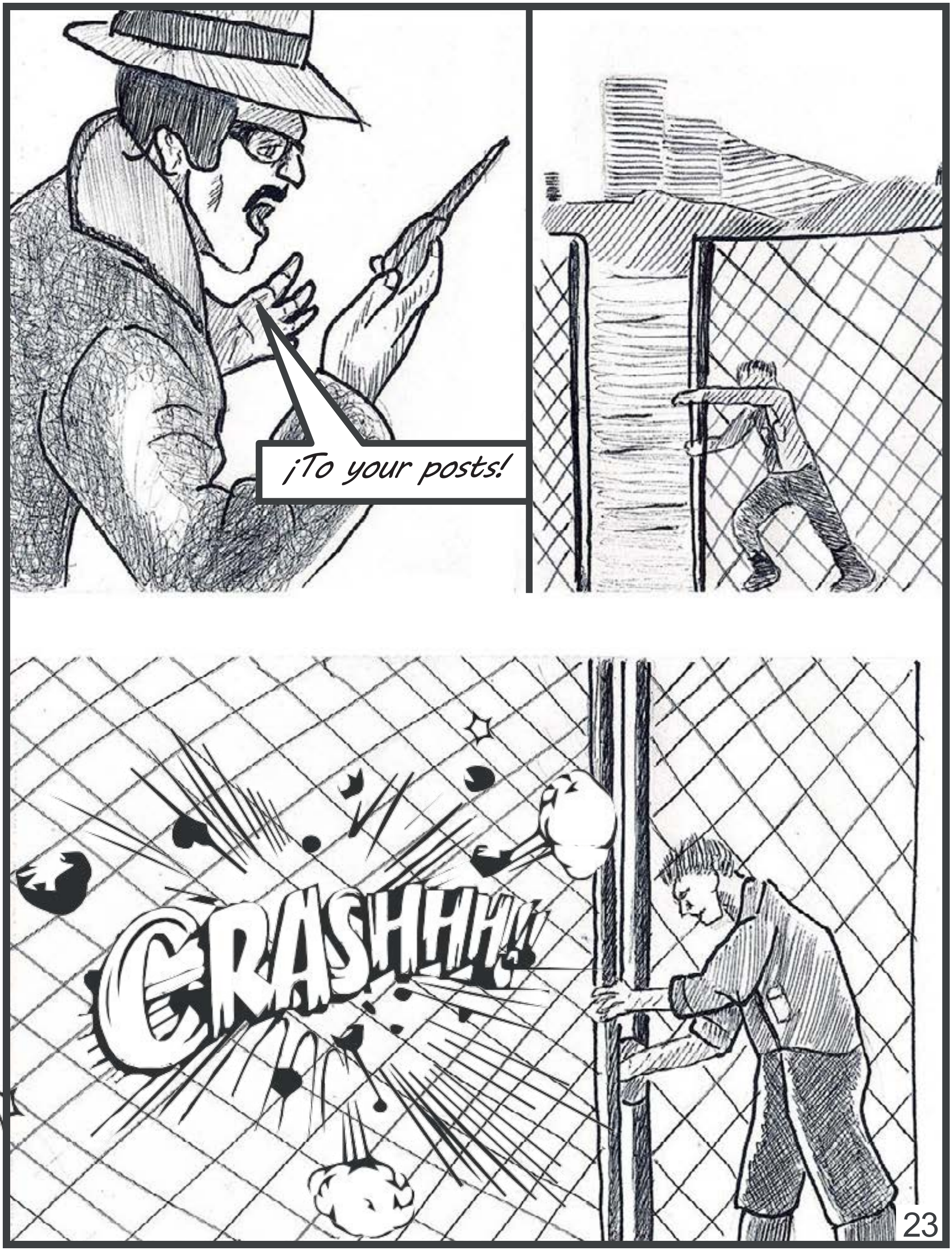

That is why we give our full effort to maintain this place.
Here someone is doing everything wrong and we are going to find him.
And there aren't new workers that can make these mistakes?
When new employees are hired we always supervise them.
UNAM
19

Several of our fellow workers have seen a man dressed as gardener that they are unable to recognise but when they try to approach him, he always runs away.


It is clear that the criminal is hiding on the premises, pretending to be a gardener to pass unnoticed and commit his atrocities!
How will you catch him?
I think I have a plan, but we need your help.
UNAM
21


Next afternoon...

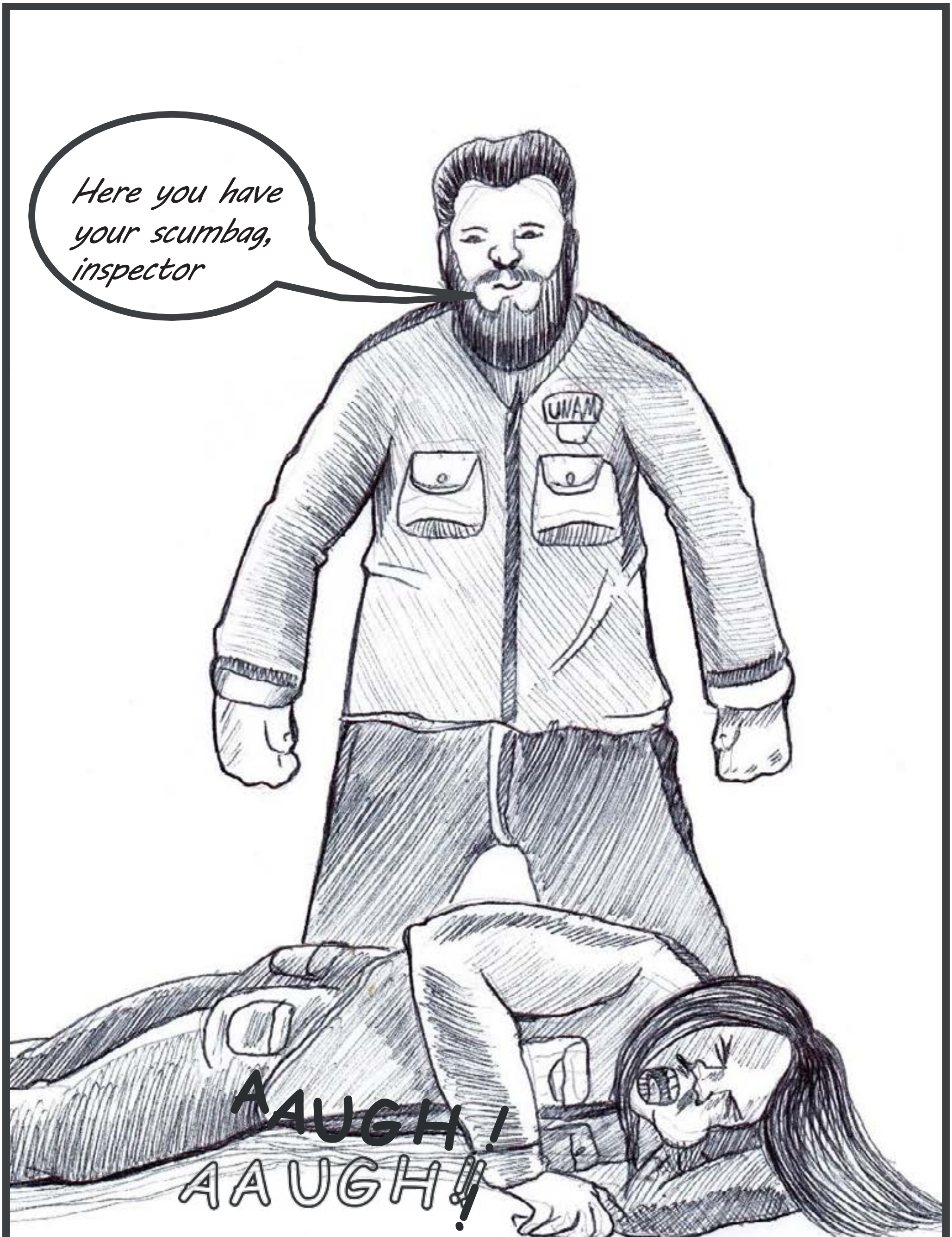

Be ready, the subject is heading to the trap,


¡To your posts!
CRASHHH!
23

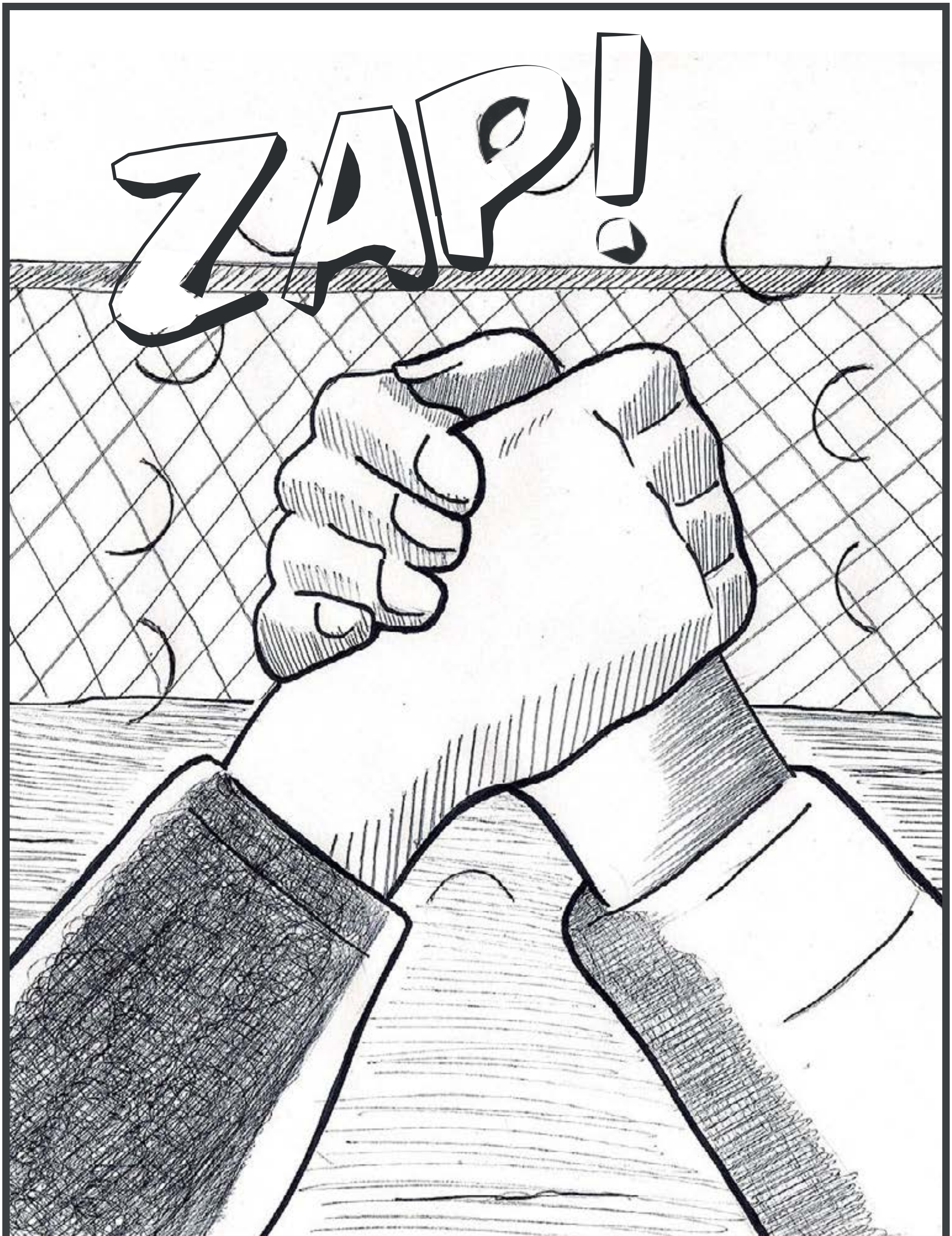

Don't move! Surrender!
mmm...
KA-POW!
AAARGH!


You are finished
Jejeje...


Where do you think you are going?
Ha Ha!
KA-POW!
27


Here you have your scumbag, inspector
UNAM
AAUGH!
AAUGH!!


Thank you so much, without your help we would have been unable to catch him.
UNAM
29


ZAP!


Sometime latter...
That is how with the help of my crew and the inspector we were able to catch the criminal.
Impressive! And now we can be safe here and enjoy the place.
Yes, but we have to continue acting to preserve the biodiversity of this place, saving the water that we will need.
31


This is a task that you, as well as us, need to keep doing!
UNAM
FIN

Appendix II

Questionnaire

1. When a handful of soil breaks down easily, it can be due to…
a) The water that it contains is polluted.
b) It has too much water.
c) It lacks water.
d) The soil is not good.

2. What do grass and native plants of *El Pedregal* need to survive?
a) Grass: watering and maintenance; native plants: maintenance
b) Grass: watering; native plants: maintenance
c) Grass: maintenance; native plants: watering
d) Grass: watering and maintenance; native plants: watering

3. Overwatering is not a good idea for: water conservation and plants.

4. What are the benefits of having native plants of *El Pedregal* in our campus? They preserve the local ecosystem as well as help in saving water.

5. For how long should gardens of our campus be irrigated? For no more than half an hour.

6. What happens if they are irrigated for longer periods? The soil gets saturated and water. drains.

7. If you lived in a city where water is scarce and your house had a big garden, which actions of those presented in the comic book The Impostor would you carry out to decrease water consumption in irrigation? I would substitute plants with high water demand for native plants.

8. How would you know if you are using too much water in irrigation? I would take a handful of soil and see if it breaked down, which would mean that it was oversaturated with water.

CONTRIBUTORS

Marianne Achiam is an associate professor at the Department of Science Education, University of Copenhagen, Denmark, where she leads the research group on science communication. Her research investigates the processes by which the science of scientists is embodied in science communication initiatives and activities (e.g. exhibitions, talks, workshops, festivals) to ultimately become the science of the participants. In recent years, her focus has been on wicked sustainability problems, and the implications of sustainability for science communication research and practice. Her teaching is closely linked to her research, and seeks to provide students with competencies and self-efficacy in communicating sustainability science to make a difference. She has published her research in international, peer-reviewed journals in the fields of science communication, museology, and science education, has authored several chapters for peer-reviewed edited volumes, and has edited books published by Springer and Routledge.

Fabiana Battisti has a PhD in communication, social research, and marketing at Sapienza University of Rome. In 2023, she was a visiting scholar at the Africa Media Matrix School of Journalism and Media Studies at Rhodes University in South Africa. Her work dialogues with journalistic coverage and digital activism on dis/ability and the framing processes involved in the construction of social representation. Her main research interests include media, diversity and decolonization, journalism, digital and participatory culture, and science communication. Several of her papers have been have presented at national, European, and international conferences (e.g. ICA and IAMCR).

Federica Beduini is training as a high school teacher and participating in the ExE program of the Empieza por Educar foundation (part of the Teach for All network), which aims at fighting inequalities in education. In the last eight years, she has been a member of the outreach team of ICFO (Institute of Photonics Science near Barcelona), coordinating citizen science experiments and the outreach activities directed to the general public and schools. She obtained her PhD in Photonics with a project on experimental quantum physics at ICFO in 2015.

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Marco Bruno is an associate professor at Sapienza University of Rome in the Department of Communication and Social Research. He teaches the courses Sociology of Communication and History and Models of Journalism. He is chair of the three-year graduate program in public and corporate communication and member of the teaching board of the International Joint PhD in social representation, culture, communication. His approach aims to understand how the media frames knowledge and the representation of reality, with research focus mainly on the analysis of journalism and information, media and diversity, political and electoral communication, political phenomena and participatory practices. He is the author of four books and has published many contributions in national and international journals and books.

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Noemi Crescentini is a sociologist and PhD candidate in social sciences and statistics at the University of Naples Federico II (Italy). She was a visiting scholar at the Competence Centre Citizen Science affiliated with the University of Zurich and ETH Zurich. In addition to the communication of science and citizen science, her research interests concern the connections between science, technology, and society.

Petra Černe Oven is a designer, theoretician, and author with a special interest in typography, information design, and the theory and history of visual communication design. She completed her PhD at the Department of Typography and Graphic Communication at the University of Reading (UK). She has initiated or co-organised over forty conferences, workshops, and exhibitions, and has published extensively in academic and professional media. Since 2010, she has been co-editing Zbirka 42, a series of books on design theory with dr. Barbara Predan. Černe Oven has served as a member of numerous juries nationally and internationally (TDC NY, European Design Award), is a country delegate at the Association Typographique Internationale (ATypI), and lectures internationally. She is a professor at the Academy of Fine Arts and Design of the University of Ljubljana where she serves as the head of the Chair of Theoretical Studies.

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Simon Goorney is based at Aarhus University, Denmark, and manages European projects in Quantum Technology (QT) education and outreach, including Europe's largest QT Master, DigiQ. In these capacities, he researches the challenges facing the emerging QT industry, including the need for careful communication to ensure that technology is adopted with minimal mistrust and misinformation.

Dejan Jontes is an associate professor of media and communication studies at the Faculty of Social Sciences of the University of Ljubljana. His research focuses on popular television forms, cultural approaches to journalism, and, more recently, science communication in transition countries. His articles and book chapters have been published in the journals *Media and Communication*, *Cultural Studies*, *European Journal of Cultural Studies*, *Anthropological Notebooks*, *Two Homelands*, *Comedy Studies*, and others.

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