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Chapter 15

Deep and Meaningful: An Iterative Approach to Developing an Authentic narrative for Public Engagement for Plant Molecular Technologies in Human and Animal Health

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Abstract Public acceptance of Plant Molecular Farming (PMF) for therapeutic and industrial proteins is a contentious public issue with stakeholder concerns focused on the social, environmental, and regulatory challenges surrounding their development. For the public, cross-pollination with food crops, safety, the potential side effects on human health and, regulatory and policing issues are areas that require careful consideration when balanced with the benefits of the technology. Moreover, there is public concern over transparency and the role of business, the motivation for profits and the ownership and access to PMF technologies. With this background, Pharma Factory, a four-year EU funded research project from the Horizon 2020-Biobased Innovation for sustainable goods and services call, is investigating new ways of producing pharmaceuticals. Concomitantly, the work is tasked with 'public engagement' to explore barriers to acceptance of PMF pharmaceuticals for human and animal health. In this chapter we present the research undertaken to achieve the main objective of 'public engagement', the value of the process for stakeholders and Science and Technology partners. The approach incorporated a variety of perspectives and the development of many tools, including visuals, a glossary, an icon language, a narrative animation, posters, and interactive exhibits, all relating to the perceived value and concerns of the technology under development, highlighting lived experiences of those who would be the recipients of the technologies. This extensive methodological approach not only builds scientific capacity and curiosity, through a process of participatory deliberations but also offers a rich story around the technology which, we argue, provides the circumstances for a 'deep and meaningful' dialogue with the public and an authentic voice which has a legacy beyond the public engagement inside the funded project. Crucially, as the subsequent sections reveal, the public engagement story did not shy away from or 'hide' inconvenient questions or concerns, but rather highlighted them as opportunities for further discussion.

Keywords Co-design, Public Engagement, Design methods

0.1 Introduction

Plant Molecular Farming (PMF) offers new ways of researching and producing medicines, for vaccines, diagnostics and treatments in human and animal health. However, because of public opposition to Genetically Modified Organisms in food production there has been an inadvertent impact on other areas of bioengineering including PMF. Although there is less opposition towards these technologies for human health, there is still public concern that has crossed over from the GMO debate and impacted on the public's acceptance of these medical products.

Against this backdrop, Pharma Factory was a four-year EU Horizon 2020 Innovation Action research project which took place between 2017 and 2022, which was tasked with developing medical, veterinary, and diagnostic products for human and animal health using Plant Molecular Farming technologies. Included in its programme of work was a diverse range of stakeholder engagement activities, to explore issues around social acceptance and resistances to these Plant Molecular Farming (PMF) products. To situate and frame the Pharma Factory stakeholder engagement, this chapter offers in the first instance, an overview of the rationale for the emergence and evolution of public engagement in scientific communication that developed in response to advances taking place in areas such as biotechnology. We then explain our methodological approach, in response to the different plant molecular technologies under development, and the use of co-design methods that were conceived as a dialogical and deliberative process that would embrace different ways of knowing amongst a diverse range of stakeholders such as patient groups, healthcare practitioners, clinicians, technology developers and the wider public. From the start we designed the different steps of the research process to be iterative, to inform the follow-on engagement activities and to ultimately frame the content and activities for three public exhibitions.

Throughout the project the focus of stakeholder engagement has been on building scientific capacity and criticality in relation to the Pharma Factory products as a process of co-creating knowledge to better engage with issues around public acceptance. Thus, dialogue with a range of publics became central, not as an exercise to build consensus around (PMF) per se, but to meaningfully engage different groups, using co-design tools in ways that would be human centred, future-facing, and account for a diversity of citizen concerns and values. The co-design stakeholder engagement workshops enabled the emergence of concerns and values that were communicated through a series of interactive public exhibitions during 2021 and 2022. The findings from these various engagements suggest that the public are open to dialogue and, far from being resistant to PMF, are motivated to actively develop their knowledge so that they can better understand these technologies, not as sensationalist either or options but as part of more entangled range of personal and systemic issues that account for the complexities and trade-offs that need to be considered. Moreover, we found that this approach allowed an authentic narrative to evolve, which reaches beyond the assumptions of technology developers and enables meaningful dialogue with general audiences.

0.2 Background – shifting perspectives

From the 1970s through to the end of the twentieth century, the model for scientific communication with the public was constructed as a 'deficit' model (Wilsdon and Willis 2004; Stilgoe et al. 2014) in which 'the public' were imagined as ignorant, hostile to scientific developments, and presented as a hindrance and obstruction to scientific innovation. In this instance scientists in white coats held authority and respect, with part of their professional responsibilities extending to improving the public's understanding and knowledge of science (Wilsdon and Willis 2004). In contrast, at the start of the millennium, with developments in information technologies, the increase of access to information and the scientific fall-out from BSE, there were calls for more scientific openness and better scientific governance (Irwin 2006). According to Wilsdon and Willis (2004) this change in perspective can also be attributed to the changing boundaries of science and business which, although never completely delineated, were becoming more entangled in business, societal and political relationships. For the authors the consequence of this was a growing "wariness towards scientists working in industry and government, and a suspicion of private ownership of scientific knowledge (Joly and Rip 2007)." To address this both Europe (European Commission 2001) and the UK (House of Lords Select committee 2000 on Science and Society) sought to overcome this legitimization crisis by pushing for greater public engagement in scientific developments (Irwin 2006) in areas such as genetic engineering. However, Irwin notes how this rhetorical shift to a scientific governance based on public dialogue, transparency and democratic agency was similar to the previous deficit model of understanding, with this push for transparency and openness being an equivalent form of scientific authority, convincing a sceptical public of the need to trust decision makers in their expertise, objectivity, and impartiality. Thus, for Irwin, instead of the previous top-down approach to address public ignorance the new form was still based on an information deficit model only this time, the deficit was a lack of trust. This shift from 'deficit to dialogue' for scientists, funders and policy makers is further critiqued by Stilgoe et al. (2014) as they question the validity of the approach in challenging and changing more fundamental structural institutional issues of science and its governance and see it as potentially reinforcing incumbent power structures (see also chapter "Biopharming's Growing Pains").

With much of the scientific research coming through taxpayer funding, Marris and Rose (2010) argue that the public should by necessity be involved in scientific decision making relating to the technology and its governance. In other cases, they too reiterate the need for public consultation as part of a process of building trust and additionally smoothing the way for new scientific innovations; ideally with the engagements taken early in the development to truly influence the direction of the work (Joly and Rip 2007). Yet, the authors stress that such approaches are not without tensions and opposition, and they should not be seen as exercises in agreement and acceptance. Instead, it is recommended that such encounters are framed as an opportunity to understand and recognise multiple viewpoints and to ultimately assist decision making by accommodating different perspectives (Joly and Rip 2007). However, scientists have raised doubts about the capability of the public to contribute to scientific decision making, especially if they are lacking scientific knowledge and expertise (Graur 2007). Equivalently, citizens and third sector actors' question and doubt their knowledge and skills to engage in participatory activities in science, technology, and innovation (Dreyer et al. 2018).

For many scientists, the opposition by the public to GMO is attributed to a lack of appropriate knowledge, which also relates to doubts that scientists may have on the public's ability to be involved in scientific decision making. For most of the time, people operate rationally on intuition which occurs unconsciously, until we are confronted with abstract and complex scenarios that will then lead to irrationality (Blanke et al. 2015). For the authors this irrationality occurs when ideas and concepts require effort and time to understand, with only education offering a solution to the entrenched biases. Furthermore, the authors argue that this irrationality comes to the fore when negative images and campaigns such as those presented by anti-GMO campaigns, work to undermine public trust, for example by linking socioeconomic abuses to GM products whilst also playing to notions of unnaturalness and contamination of the environment (Blanke et al. 2015). In contrast, Couée (2016) sees this argument as too simplistic and instead of pitching scientists and citizens as rational and irrational against each other, suggests that an alternative approach is taken that accounts for the complex interactions between biotechnologies, societies, industry, and capitalism. In many instances what is in fact being exhibited is not irrationality but empirical scepticism and that such complexity should be seen as a stimulating intellectual challenge (Couée 2016). MacPhetres et al. (2019) also make the connection between a lacks of specific scientific domain knowledge of GM technology as a predictor of attitudes to GM foods. However, acceptance can be improved by teaching people about the science behind GM foods which leads to more knowledge and positive attitudes towards the foods, a greater willingness to consume the foods and to view them as less risky (MacPhetres et al. 2019). To achieve this, they argue that the information communicated must be presented as value neutral that is avoiding any ideological claims that GM are safe or good. By adopting this approach participants are then encouraged to reflect about the information presented and to make their own decisions. Similarly, the authors point to the contribution of mechanistic knowledge of scientific processes so that participants build foundational information to support their decisions on whether a technology is safe or not. Overall, the authors recommend that communicating GM information in an engaging and accessible format to facilitate decisions is an effective way to build public engagement of these technologies and by addressing gaps in knowledge, public opposition and acceptance may be critically informed.

0.3 Co-design for empathetic and flexible stakeholder engagement

An alternative perspective to public engagement for the purposes of scientific governance and scientific decision making (Irwin 2006; Stilgoe et al. 2014) and one particularly salient to our work, is offered by Selin et al. (2017). The authors note how public engagement for scientific governance, as a focus for scholarly research, is often criticised for producing questionable outcomes that are limited in their impact on scientific governance policies, through their various engagement processes (Stilgoe et al. 2014). Consequently, this has diminished other modes of public engagement that have weak or non-existent ties to governance models, such as science cafes, festivals, informal dialogues, or online-discussions. To counter this, the authors look instead to citizen capacity building by drawing on literature from other domains of scholarship such as public administration to offer additional perspectives on the value of engaging publics. For Brodie et al. (2009) the rationale for participation in local and national governance are interconnected with the involvement offering a range of benefits from legitimacy and accountability of democratic institutions; empowering communities by coming together around a common cause or interest which can assist in building social cohesion and as a tool for reforming public services that are more responsive and suited to people's needs.

Concurrently, much citizen engagement in these public administration contexts have looked to design research and especially co-design for its ability to deal with complex issues and to create active citizenship to address many of the systemic problems of late modernity (Buchanan 2001; Norman and Stappers 2015; Evans and Terrey 2016). Since the millennium, as an emerging and evolving practice, service design has been very much at the forefront of design's adoption within policy and local government (Bason 2014; Kimbell 2015) and with it the use of co-design as a methodological approach. Evans and Terrey (2016) see co-design as "a methodology of research and professional reflection that supports inclusive problem solving and seeks solutions that will work for people." Concomitantly by adopting these methods, the authors see opportunities for building trust with citizens and stakeholders, facilitating knowledge of policy and identifying delivery problems that public organisations do not possess. However, in formulating more relational government services, standardized approaches for tackling systemic and complex problems are less effective as in-depth knowledge of personal circumstances is required (Muir and Parker 2014).

Co-design's role in Responsible Research Innovation (RRI) is explored by Deserti et al. (2020) who highlight its designerly methodological characteristics, which are iterative, experimental, human centred, and supported by prototyping. The application of these methods arose from the RRI framework (CNR, EU Commission 2015) that aimed to draw on a range of "societal actors – researchers, citizens, policy makers, third sector organisations to collaborate during the research and innovation phases in order to better align both the process and its outcomes with the values, needs and expectations of society and to engage citizens and end users in the co-creation of the solutions they wish and need (Rizzo et al 2020)." By using such methods, the authors note how the practice takes policymaking beyond its more utilitarian approach of problem solving with experts, to a space which enables a better alignment between the technology and the situated nature of the context in which a policy will be implemented. In such experimental environments, stakeholders may be engaged in new and far-future-making with the technology, mapping their own current experiences and relationships, including those with the technology, whilst exploring concerns over the social, safety and risk dimensions.

Specifically relating to the biosciences and Plant Molecular Farming, Hornbuckle et al. (2020) present design as distinctly different methodology from the biosciences and social sciences, offering something fundamental that science communication has been missing. For the authors, design attributes are seen as being "flexible, problem-orientated and empathic, with co-design providing the tools to build a bridge between the highly specific but conceptually abstract science with its codified language, and the values of specific stakeholder or wider audience (Hornbuckle et al. 2020)." Similarly Michael (2012) sees designerly public engagement as to be thoughtful within a context of complexity, in contrast to other forms of public engagement that aims to channel public opinion into existing institutions to influence policy making. Consequently, material objects used in public engagement from a design perspective are thus "meant to evoke in their audiences less a need for clarity, than a desire for, and exploration of complexity (541). Describing design's role further within these co-design processes, Hornbuckle (2022) expands and reflects on the contribution of design as changing proximities between different actors. Recognising the complexity of a multi-stakeholder system where pronounced distances and differences exist between expert knowledge and the lived experiences of different stakeholders such as patients, healthcare practitioners and the wider public, the author recommends a range of codesign methods to facilitate knowledge flow as a set of translatory practices to build closer proximity.

For the purposes of our research, Pharma Factory focused on stakeholder engagement as informed by service design (Hornbuckle et al. 2020) rather than public engagement to account for the mix of the audiences that we would be interacting with. The overall structure of the different research phases was also designed to be highly iterative with each phase informing subsequent activities and culminating in the final public exhibitions. This research frame offered an experimental and flexible dialogical approach involving iterations and prototyping possible futures through individual experiences. It also created a relational and human-centred perspective that accounted for the lived experiences for the people with health conditions that would be affected by the Plant Molecular products under development. In the following section we present the co-design methodological steps undertaken to build scientific capacity and curiosity for stakeholders, to build confidence and criticality when engaging in issues of acceptance on NPBT.

0.4 Methodological approach

Increasingly, emphasis is being placed on 'public engagement' by funders of Science and Technology (S&T) Innovation projects. However, as described in the Background section of this chapter, public engagement can take many different forms, varying in the approach, the resource invested, the time taken and the involvement of different viewpoints. In the case of Pharma Factory, social scientists and design researchers proposed that, rather than rely on assumptions about the potential value of the technology to stakeholders, the project could adopt an iterative methodological approach which aims to build dialogue between technology developers and stakeholders through a series of workshops and ultimately build scientific capacity around PMF. This would have a multiplier effect: building trust with stakeholders (such as patients and HCPs), better understanding the value and therefore being able to communicate more effectively with the public, developing an authentic narrative, and providing technology developers with insights about the value of their products to inform their future work. This iterative methodology is diagrammatised in Fig. 1.

The iterative process adopted in Pharma Factory involved three phases which were executed using a mixed methods approach. Site visits and literature reviews were conducted in Phase 1 in preparation for the stakeholder engagement workshops in Phase 2. Design researchers from University of the Arts London (UAL) applied their expertise in co-design tools and methods, while social science researchers from St George's University of London (SGUL) undertook a series of partner and patient interviews typical of a social science methodology. The combined approach of the two disciplines was an important feature of the approach; the research team felt that this would strengthen the methodology as well as build trust in the research (for example that a University Hospital was involved in research involving patients). Each discipline's role is coded within the diagram in Fig. 1. In phases 1 and 2 of the research process the qualitative social science research and the co-design workshops contextualised the S&T researchers understanding of public perceptions and the opinions of sections of the public about PMF processes and products. In addition to the data collection phases, there are important 'in between' moments of analysis, synthesis, sensemaking, translation and tool development in preparation for the next set of engagements, including the final phase involving interactive public exhibitions and partner feedback. This typifies the reflexive and responsive approach of design research and some modes of the social sciences.

Fig. 1: WP2 workflow diagram

Table 1 outlines full range of activities undertaken during the three research phases to meet the objective of 'public engagement'. The details of the research methods are described in the subsequent sub-sections. Due to the COVID-19 pandemic some of the planned activities had to be cancelled, postponed or moved online. The greatest loss to the process were the public engagements planned in Phase 2, which were intended as 'pop-up' events, but due to COVID-19 social restrictions were not permitted by national and local authorities at that time. The activities which could not take place are greyed out in Table 1.

Table 1 Co-design stakeholder workshops completed

Activity Date/s	Participants	Organisation (project partners /external)	Activity type
PHASE 1: Preliminary Work 11/2018 – 02/2020			
	n/a	n/a	Literature Review
	All WPs	Representatives from all S&T WPs	S&T scoping interviews
	n/a	SGUL (UK); Leaf systems (UK); Fraunhofer Institute (Germany); Transalgae (Israel); Samabriva (France) (all project partners)	Site visits
	CEO	Leaf Systems	Discussion
	Members of the public (SGUL campus, St George's hospital, and London College of Communication campus)	SGUL	5-minute person-on-the street interviews to understand knowledge of and perception of PMF process and products
		SGUL; UAL	In-person exhibition at design festival
PHASE 2: Research & Engagement			
S&T partner engagement			
January 2019	WP3	VTT, University of Rouen (UoR), CSIC, SGUL,	Eco-systems, Values, Persona Pitches & Prototypes

	WP4	Fraunhofer, CSIC & SGUL	Ecosystems, Personas, Service storyboard & Innovation Canvas
March 2019	WP5	UCL, Transalgae, SGUL	Eco-system, Values & Innovation Canvas
January 2019	WP6	UoR, Albajuna, Leaf Systems, Frauhofer, Samabrieva, SGUL	Ecosystem, Values, Persona pitches, Prototypes, Regulatory timeline, Innovation canvas & Storyboarding
March 2019	WP7	SGUL, Leaf Systems, Diamante	Ecosystems, Personas, Service storyboard & Innovation Canvas
Co-design with public [not possible due to lockdown measures]			
Stakeholder engagement: 02/2020 – 06/2021			
26/02/2020	IMD Pharmacists N=8	British Inherited Metabolic Disease Group (UK – external;)	In-person workshop
29/06/2020 - 03/07/2020	Rheumatoid Arthritis Patients N=13	British Rheumatoid Arthritis Society (UK - external)	Online (asynchronous) workshop
14/09/2020 - 18/09/2020	Sjögrens Syndrome Patients N=8	British Sjogrens Syndrome Association (UK – external)	Online (asynchronous) workshop
16/12/2020 - 20/12/2020	HIV Patients N=7 N=4	ABRAÇO; Fundacao Portuguesa a Comunidade contra a sida (FPCCSIDA); Associação Positivo; Liga Portuguesa Contra a SIDA; Grupo De Ativistas em Tratamento (GAT); SERES (Portugal – external)	Online (asynchronous) & in-person workshop
17/05/2021 - 14/06/2021	Conscious consumers N=5 (UK)	Personal networks (UK, Spain, France, Italy - external)	Online (asynchronous) workshop

	(survey: N=39 UK N=13 ESP N=11 FRA)		
PHASE 3: Communication and Dissemination			
Public Exhibitions			
07/10/21 - 09/10/21	School children, university students	Rouen Fete de la Sciences at Rouen University (French)	In person exhibition stand at science fair
25/10/21 - 30/10/21	Families	Norwich Science Festival, Norwich UK, in English	In person exhibition stand at science fair
6/07/22 – 7/07/22	Patients, university students, healthcare workers	SGUL	In-person exhibition in university-hospital
S&T Partner Feedback			
17/06/22	Project partners n=5	**Samabriva,** CSIC UofR, SGUL	Online focus group
14/06/22	Project partners n=6	**Transalgae,** UCL	Online focus group
14/06/22	Project partners n=4	**Albajuna,** UoR VTT, Leaf Systems	Online focus group
21/06/22	Project partners n=4	**Diamante,** SGUL, Leaf Systems	Online focus group
			Online focus group

0.4.1 Phase 1: preliminary work

Design researchers undertook a period of primary and secondary research in the form of a literature review, field visits, telephone interviews and the co-development of a project glossary with scientific partners. The purpose of this phase was to develop the literacy of the design researchers in the technology, to better understand and make sense of the technologies, their potential benefits and the challenges to implementation. Field visits to the technology sites allowed design researchers to gather experiential knowledge, which helped them to understand the processes better, recording these in various media such as photographs, field notes and sketches, methods typical of an anthropological approach. In turn, this enabled researchers to translate the complex scientific information into appropriate language and develop a narrative so that stakeholders can quickly understand and 'access' the concepts presented by the technologies. For example, concepts such as 'transient expression', ‘diagnostic kit’ or ‘genetic modification’ are relatively simple for a scientist to rationalise, whereas non-scientists may have little or no knowledge of these concepts, or they may have a viewpoint formed from media sources which often present a bias and doesn’t convey the ‘facts’ or context to the audience. Therefore, the challenge for design researchers was to try to reveal and communicate ‘truths’ about these concepts, based on scientific information, so that participants in the research can understand the context quickly and effectively within the workshop setting, and can respond with a more accurate reflection on the value of the technology to them. This phase overlapped the beginning of Phase 2 as needs arose during the process, in this way the approach is reflexive, responding to themes emerging through the research.

0.4.2 Phase 2: research and engagement

Based on their experience as Service Designers and design facilitators, the researchers developed a general narrative for the workshops taking participants on a journey from their own experiences through several carefully designed steps. This is depicted in Fig. 2.

Fig. 2: Co-design narrative used in stakeholder workshops

0.4.2.1 Science and technology partner engagement

Four consortium co-design sessions were held at SGUL in January 2019 for Work Packages (WP) 3, 4 and 6 with two further workshops held at a review meeting in Valencia for WP 5 and 7. For each activity the WP consortium members collaborated with their team members to address each of the co-design tasks. The purpose of the exercise was to take the scientists through a series of deliberative and dialogical processes relating to their PMF technologies and to consider diverse stakeholders and wider systemic issues. The workshops also included creative exercises for the consortium members to prototype ideas on how these PMF platforms could have greater visibility within human and animal healthcare environments.

0.4.2.2 Partner co-design tools

The co-design tools were designed to actively engage the consortium members in situating their WP technological developments within broader more systemic frames and to consider and respond to the diversity of opinions that exist. In addition, for WP2 members these workshops were part of a sense making process to better understand how the scientists conceived the PMF technologies in terms of near and far futures, the benefits and values to different stakeholders and how the scientists could attend to the challenges of communicating the value of their technology to different audiences. The following list summarises the key activities included in each of the workshops.

- **Eco-system mapping near and far futures**: to situate the technology within more systemic frames of stakeholders, production methods, regulatory implications, and distribution channels.
- **Regulatory mapping**: to map out the regulatory pathway for each WP product, including the timeframes, and challenges for each of the PMF technologies.
- **Stakeholder values tools for near and far futures:** to reflect on how three stakeholders – a WP partner, an end-user and an influencer would be affected by the PMF technology. Questions explored: What is their need for PMF? What is the value to them?
- **Persona Pitches:** relational and empathetic tools were designed to represent diverse groups of actors who will benefit and be opposed to the technology. The consortium members were encouraged to think about the value of their technology to a persona profile and the values and beliefs that the person may have which may influence their acceptance or rejection.
- **Prototyping:** consortium members were asked to conceptualize ways in which their PMF technology could become more visible within a particular context such as healthcare and to generate newspaper headlines that would communicate the values and benefits of their specific technology.

The synthesis from these workshop activities were used to support the co-design activities with the stakeholders and frame the exhibition around the benefits and values of PMF to diverse audiences (Fig. 3).

Fig. 3: An example of a workshop output by one of the consortium teams.

0.4.2.3 Stakeholder recruitment

Stakeholders were identified for each of the four technologies under development. A wide range of the stakeholder communities identified were approached for engagement, including healthcare professionals (nurses and doctors), industry (pharmaceutical companies), health service organisations (NICE in the UK), regulators and regulatory consultants, fish farmers and veterinary professionals, and supermarkets. However, there were difficulties in engaging stakeholders for whom the value of the technology is less clear, for large organisations where there was no previous or existing contact, or where this type of engagement might be seen as low priority compared with more pressing concerns. Patients have the most to gain from new technologies and are convened in the form of patient organisations which is more complicit to recruitment in research. Vouchers were provided to participants as an incentive.

0.4.2.4 Stakeholder co-design tools

In addition to the S&T partner engagement co-design tools, a set of Relational Tools were developed for the palette of existing tools, to translate the co-design narrative into a series of activities for participants to respond to step-by-step. These were then adapted to the needs of the group of participants in each workshop:

- **'Experience gathering' tools**: these are designed to encourage participants to reflect on their own experiences, including pathways of diagnosis and treatment, diaries, educational histories, and eco-system maps (Fig. 4).
- **'Establishing understanding' tools**: these were designed to understand the entry-point of the participants to the subject, often focussing on their knowledge of how different therapies are produced, or on particular terms central to the technology, such as 'genetic modification' (Fig. 5).
- **'Explanation of the technology' tools**: based on the glossary and research conducted in the previous phase, participants were presented with a series of 'cards' which outlined key concepts in simple language and icons, such as 'how are medical proteins produced?', which positions PMF with the spectrum of genetically engineered organisms used to express proteins (Fig. 6).
- **'Perspective gathering' tools:** Worksheets with simple matrices for gathering participants' views on the benefits, concerns and questions raised by the information they had been presented with (Fig. 7). This included a specific GM Proximities tool which was used for all the workshops as a penultimate task, which is discussed later.

Fig. 4: Example of co-design tools for 'experience gathering'

Fig. 5: Example of co-design tools for "establishing understanding'

Fig. 6: Example of co-design tools for 'explaining the technology'

Fig. 7: Example of co-design tools for 'gathering perspectives'

0.4.2.5 Stakeholder engagement

We planned three-hour workshops to be conducted in a convenient location for participants, however due to lockdown restrictions only two of the workshops could take place in-person. For the remote workshops Facebook was chosen as a 'basecamp' for participants because our first group were already familiar with this platform and operated through Facebook via a private discussion group. Generally, we found that 'snowball' recruitment through Facebook was slow; we first needed to gain the trust of a 'gatekeeper' in the form of a community group who owned an active Facebook group. We invited participants to closed Facebook groups to inform them of updates, steps and to post introductory videos and links to our online collaborative space in the MIRO platform (https://miro.com/), which is free for educators to use. Facebook was useful as a meeting and discussion space when hosting the online workshops and participants were supportive of each other and actively posted questions.

The online workshops were 'asynchronous', meaning that participants were set daily 30minute tasks over a period of 3 or 4 days, but could complete them independently without the need for direct facilitation. Participant feedback was largely positive, citing that they found it less intimidating and more convenient to work at their own pace. The online workshops were more successful when participants were confident IT users, but less so for some users with limited experience. It also proved less satisfactory for Sjögrens patients who experience 'dry eyes'. We had taken measures to mitigate these issues such as preparing participants with trial tasks and checking if 'dry eyes' would make this difficult, but there were still a couple of participants who found the tasks challenging.
Participants in the online workshops were given the opportunity to attend a live Q&A with researchers. This was an important moment for them to get quick feedback to their questions when the other outputs from the research would be unavailable for some time. This was a more personal experience at the end of an impersonal series of activities.

0.4.3 Phase 3: Dissemination and communication

0.4.3.1 Workshop data analysis and sensemaking

A thematic analysis of the workshop data was undertaken using NVIVO. Thematic codes were identified by the team through an initial synthesis of the workshop outputs. Connections and differences were made between themes and topics (Table 2), where concepts and ideas recurred through the workshop materials.

Table 2 Details of the coding themes and topics for data analysis

Coding themes	Coping topics
Agency,	Conventional medicines
Choice,	Covid19
Cost, Efficacy,	Diagnostic Investigation
Human Experience (Anxiety, Certainty, Proximity, Side Effects, Stigma and Discrimination, Symptoms and Uncertainty).	Features
Knowledge (Ethics, Not known, Trust)	Genetic Modification
Learning through the workshop	How medicines work?
Safety	Manufacturing
Scale	PMF
Security of supply	

0.4.3.2 Translation from the workshops to the public exhibitions

Following the stakeholder engagement workshops, design researchers coded and analysed the worksheets, drawing out the key themes that could then be translated into meaningful content for the public exhibitions (Table 3). The following research questions were central to this phase of sensemaking and translation:

- What is the perceived value of these technologies for the stakeholders?
- What are the main barriers to acceptance identified by the stakeholders?
- What are the stakeholders' main questions and concerns, and how might we best frame the exhibition content to address these?

Table 3: The key topics drawn from the co-design workshops that were then used to inform the content of the exhibition posters.

Co-design Workshop Key Issues.	Poster Content
Patient lived experience	Conveying the patient journey
Time and uncertainty	The benefits of how PMF may alter diagnostic, treatment and choices in human healthcare.

Gaps in understanding the technologies and medicines more generally.	Types of PMF techniques as a key thread throughout the posters.
Safety	Conveying the containment and secure facilities of the growing and processing of PMF and regulatory pathway.
Food security and health.	New ways to administer vaccines in human and animal health.
Build knowledge that counters the sensationalist approach in the media.	Communicate the human, production, and pharmaceutical opportunities.
Ethics and ownership in pharma (Exhibition 3 only)	Engaging with the debate over who should invest in PMF and other ethical considerations

The main challenge in sensemaking and translating the research for a general audience was to represent the rich data collected around stakeholder experiences and perspectives, whilst also telling the story of the project and the science. The research team were also mindful that the exhibition content had to be communicated in language that a lay audience could understand and relate to and delivered using methods that would engage and stimulate discussion. Therefore, the approach was to take visitors on a journey through a series of themed posters, whilst also providing interactive activities as a ‘way-in’ to the more detailed information for a diverse range of visitors. This also enabled a dialogical approach to the engagement, with a key aim of the exhibition being to enable conversations between the exhibition stand ‘hosts’ and the visitors. The posters needed to be easy to access out of sequence. For example, if a scientist on the stand was explaining the use of PMF to develop a diagnostic kit, they should be able to refer to the poster about benefits for patients with Sjögren’s Syndrome and Rheumatoid Arthritis.

Personas, a method typical of Service Design and co-design, were developed from the stakeholder engagement, and added a relatable ‘human dimension’ to help the public to understand how each technology may transform an individual’s life. An ‘icon language’ was commissioned to create and articulate a visual language that could be understood and interacted with at different points in the exhibitions. This was used throughout the exhibition to aid cognition and familiarity and help visitors to make connections between the different elements. An animation was also commissioned and shown on the exhibition stand, to broadly explain in an imaginative way the two different plant molecular techniques used – transient expression and transgenic – used in Pharma Factory; a French and English version was produced. Here the longevity of WP2 outcomes was also taken into consideration, as the animation could be used in many different contexts after the funding period. These are available for download from the Pharma Factory website https://pharmafactory.org/.

Following the exhibitions, all individuals who hosted the stand and engaged with members of the public who were visiting were invited to provide feedback, which is discussed in the following sections.

0.5 Science and Technology Partner Feedback

This involved presenting the findings from the stakeholder engagement to the S&T partners so that they could reflect on the implications for their future work during an online focus group that was recorded and transcribed. This was also an opportunity to receive feedback on the value of the process undertaken. This data will be considered, along with the feedback from the exhibition hosts, in the discussion in the next section.

0.5.1 Results and Discussion: the value of a deep and meaningful narrative

The multifaceted approach taken prior to reaching the final objective of 'public engagement' included the diverse range of actors in in-depth activities to explore from their perspectives as scientists, patients, healthcare experts or as members of the public the opportunities for PMF and their concerns. As part of this process, the research explored new ways of representing PMF through the development of participatory tools, visuals, a glossary, an icon language, an animation, posters, and interactive elements. These methods not only built scientific capacity around the technical mechanisms of PMF it also enabled participants to critically reflect on their current knowledge and its sources. Furthermore, the co-design methods offered a 'deep and meaningful' dialogue with the public which did not avoid or 'hide' difficult or inconvenient questions or concerns, but instead created deliberations around societal challenges, personal stories, and opportunities for further discussion.

The following section presents the data collected about the value of this methodological approach to four stakeholder groups: Patients, Health Care Professionals, General Audiences (publics) and Scientists (technology developers). This data is based on the small sample of participants in our research and is therefore not generalisable as such, but provides insights into the value of this approach so that we can confidently propose 'public engagement' recommendations for future S&T Innovation projects and applied science more generally which incorporate Relation Tools for Meaningful Engagement through an iterative process of Translation and Sensemaking as described in the methodology and illustrated as a core framework in Fig. 8.

Fig. 8: A dialogical and iterative framework for Deep and Meaningful Public Engagement, based on codesign principles and practices

0.5.2 Value to scientists at the start of the project

The Pharma Factory scientists were unfamiliar with co-design methods, and this is reflected in their responses to the process used at the early stage of the research but it is important to note the less sceptical tone by the end of work when they are well versed in this dialogical and deliberative approach:

"I found the activities very interesting. This helped us identify points we will probably need to take into account in the future. I'd like to know how this information is analysed and which conclusions can be taken from that."

"Great work, and a relaxed way to contextualise the work."

"Interesting exercises, regulatory issues identified as key. Need to define next steps. A meeting with different stakeholders seems to be necessary."

"Timeline activities helped with awareness of key stakeholders".

"Innovation and storyboard discussions were very helpful tools to understand the needs of the company and the existing barriers to PMF".

0.5.3 Value to patients, health care professionals and general audiences

Many of the participants reported that the workshops had enabled them to reflect on their own experiences and reveal aspects of their healthcare journey which hadn't come to the fore previously.

"I learned more about myself than about the project per se but the scale and scope of GM plants as biomarkers is just beyond comprehension and it's a thrill to see out of the box thinking applied to our autoimmune issues of diagnosis and hopefully treatment in the longer term." (Patient)

Furthermore, the workshops raised awareness of the scientific research and gave a voice to the patients in assessing the value of something that could impact their lives, which they apparently hadn't experienced before:

"It was great to know that researchers actually went out and talked to ordinary citizens to understand their concerns. My trust in science strengthened further."

One finding from the research is that the co-design stakeholder engagement both revealed and enabled multiple dimensions of learning and agency: about the self, and an awareness of the wider healthcare eco-system.

Most participants had very little prior knowledge of how medicines are made, even amongst the pharmacists and revealed that they put their trust almost entirely with the regulatory and healthcare service organisations. The information provided through the workshop in most cases enabled people to understand the role of genetic engineering and rationalise the role of PMF. However, in some cases this was not enough for people to understand that using plants didn't necessarily remove the need for animal testing during the process of development and regulatory approval. However, participants reported that the workshops had raised questions about the way that medicines are produced, which may impact their future actions:

"Really interesting workshop: learnt a lot and raised awareness of PMF! Made me reflect on current transparency of how drugs are made and what info should be given to patients. Good to be made aware of what future drug manufacturing could look like." (Pharmacist)

Participants reported that the workshops had challenged their previous views of GM:
"The most value to me is having my misconceptions about GM plants usage in medicine challenged and taken forward" (Patient)

"I had to reassess my views on GM and ask myself why I had the opinions I had and how they were formed. It was a good personal exercise." (Conscious consumer)

From this research it is apparent that stakeholders need reassurance about the steps being taken to avoid negative impacts of PMF on the environment and on human health. There is also a wider topic relating to trust in the profit-driven companies that use the technologies, which may be harder to address. Importantly, providing participants with more accessible information about the context in which GM technologies are used and why, enabled them to rationalise the safety and value for themselves and challenge the views that mainly form through sensationalist media reports.

Therefore, a clear value to these participants was access to scientific knowledge and rationale which allowed them the agency to do their own research, to improve their own understanding about medicines and how they are made, and about themselves and their medical condition. In the case of the stakeholder workshops, participants also exhibited confidence during the expert Q&A allowing them to ask pertinent questions on a topic they knew nothing about previously. During the partner feedback sessions, scientists were surprised that people wanted to talk to them about medicine production:

"I think what is an expected to me is like actually people want to communicate with scientists. So because like when we come up with new ideas, in most cases it got rejected by the public because people are more concerned about risk and environment impact. But actually they want to talk with scientists"

In the case of the exhibitions, the authentic narrative allowed members of the public to engage in dialogue with experts when visiting the exhibition stands.

"A group of 3 oncology nurses, all originally from different countries in Africa, but working now in the NHS… immediately understood the problem of accessibility that we are trying to solve and the potential advantages for people in developing countries. They all became very excited about the work, stayed at the stand for at least 20 minutes, and took away copies of every postcard to share with their friends." [scientist host]

The design tools, narratives, and visualisations – developed following extensive research of the terminology and the technologies using design research methods in Phase 1 – enabled the scientists to have meaningful conversations with diverse members of the public, thus increasing this access to dialogue with experts:

"The different stamps were quite useful in illustrating the different parts of the PMF process and the products that we can make. Many of the children had heard of antibodies, cells and DNA so the stamps gave a simplistic demonstration of what these things might look like. This in turn led to conversation about what their functions were." [scientist host]

"The posters tended to be observed and read by a few of the parents and older children that had a genuine interest in the subject or wanted to find out more. By asking them "Does it all make sense?" normally stimulated more in-depth questions." [scientist host]

0.5.4 Value to scientists and technology innovation developers, project partners at the end of the projects.

Scientist hosts on the exhibition stands reported some interesting conversations with visitors, noting that the interactions led to new potential collaborations in one case:

"I spoke to a consultant ophthalmologist who noted access to anti-angiogenic antibodies for AMD could be improved through the plant system and suggested to prime collaboration with colleagues at UCL / Moorfields" (Scientist host)

The role of the discussion cards was surprising in some ways, as they became the vehicle by which the hosts exchanged knowledge with visitors, handing them out to allow people to have a quick reference for the meaning behind PMF. The PMF explanatory cards were reprinted to allow for more to be distributed. The interactive poster also allowed the hosts to bring visitors into an engagement around ethical questions, which would have been near impossible otherwise:

"I think the poster with different perspectives + red/yellow/green stickers was a hit. Was simple but very effective and I think people like being able to see how their opinion compares with others." (Scientist host)

"I'm surprised how easy it was to get people to spend time reading the participant statements and giving their opinion. There was a lot of reading to do so I was surprised people were willing to take the time." (Scientist host)

There was also some scepticism and difficult questions raised by exhibition visitors, which prompted reflection from the scientific hosts:

"The conversation that stood out for me was a woman asking me how we know our technology won't be used for unethical purposes… I thought it was an interesting question. What could one do that's unethical with our platform?" (Scientist host)

Importantly, this feedback suggests that the scientists' assumptions about public perceptions, attitudes and willingness to engage were challenged through their experiences of the exhibition, allowing them to have conversations about challenging topics that they would not have had otherwise.

In the S&T partner feedback sessions there was a general acknowledgement that dialogue can be an effective strategy towards achieving a reasonable and 'sensible' response from stakeholders and general audiences. This was one of the elements that surprised some partners, that stakeholders had been able to rationalise the use of GM within the context of PMF, in the development of therapies, diagnostics and vaccine production:

"I actually thought that most of what they said was quite sensible and quite thoughtful" (S&T partner)

There was an acknowledgement that peoples' concerns may go beyond the motivations of the scientific research and therefore understanding peoples' concerns can help to guide communication: for example, concerns over safety for people and the environment, which appeared to be based on having little understanding of the mechanisms and infrastructures in place. In the exhibitions these concerns were addressed with images of contained facilities with clear definitions of terminology, and a regulatory timeline which showed the complexity of stakeholder interactions rather than over-simplifying the process.

S&T partners developed an understanding the power of visual and narrative methods of communication for quickly and simply bringing people into closer proximity with the technology, giving access and agency. Expanding on the reported impact of including images of the secure PMF facilities, one senior scientist discussed the possibility of more interactive and hands-on experiences for members of the public.

"The stakeholders or the patients visualize, and you show them those pictures of what it means 'the contained facility'. And then what I understood is that, in a way, produced more trust on them. I'm not sure if it's because of the picture that it looks more 'under control' or is simply because they really can imagine it and they really can see it and this is this other way of connecting with the reality that is not only about reasons, but also about images, about feelings. And I think we are under-exploiting those who want to advocate technology." (S&T partner)

"I know we are scientists […] we know the pathway of rationalizing and explaining but in addition to that I think there's a group of the population, for which, [researcher] was explaining, this is probably not the main route pathway, but feeling, touching and proximity bring it closer. So, whether we like it or not this is nowadays one of the main pathways to get people acquainted or accepting." (S&T partner)

The research presented led to a general acknowledgement that alternative methods to 'science communication' are worth investing in to move the technology forward. Partners felt that the Service Design and Codesign approach had been a valuable exercise, which provided an authenticity to the public engagement phase of the project (exhibitions). For example, one partner aligned the benefits of the technology to the environmental concerns raised by stakeholders:

"one of the biggest advantages of using the oral vaccines that we are, if we are talking about the challenge of sustainability right now: we are going to replace all the needles, the gloves, the expert men that needs to be educated in order to vaccine each fish individually. So also regarding the environmental impact we are bringing a unique advantage." (S&T partner)

"The GM problem was always badly managed by the scientists and well managed by the opposers. I mean, it was basically a one-sided argument that the scientists never got involved and so it was just that 'this is bad. Stop doing it'." (S&T partner)

S&T partners developed an understanding that exploring future narratives and bringing people into that discussion can build confidence and trust: being the ones to ask the difficult questions and guide the process of answering them. This appeared to give the partners an energy and enthusiasm to explore previously difficult topics with general audiences which they might have found difficult to navigate previously. In this way, the resources created for the 'public engagement' provided the S&T partners with tools with which to engage in meaningful dialogue with stakeholders and general audiences.

"I think what you've done has been really interesting and I think it's valuable for bench scientists to realize what the public think about what you're doing. And you know there's always this perception from people working with plants that there are big anti-GM lobbies still out there" (S&T partner)

"the temptation as a scientist is always to present the science, the technology as the main story. But actually, the main story when talking to the public is you know 'this is a problem, a worldwide problem that that needs to be addressed'. And you know 'this is the regulations that we need to meet in order to address it' and then the technology you know should follow. And as [researcher] was saying, also the opportunity to talk directly to scientists to realize that actually we are, you know, rational, normal, responsible individuals and that we do consider all the risks and the benefits of what we're trying to do." (S&T partner)

As expressed in the previous quote, one finding that surprised some of the S&T partners, was that people want to talk to scientists. However, the research suggests that this was most accessible once they have been taken through the codesign process which allows them to acquire sufficient understanding to engage in meaningful and equitable exchanges.

"[the general public] get so much information and [they] don't know even if what [they're] hearing is right or wrong and so definitely to talk to the scientists would help" (S&T partner)

Finally, partners appreciated that building an authentic narrative around value as a foundation for dialogue with general audiences takes time, process and investment (as demonstrated by the Service Design and Codesign research process). However, they also recognised that this process is worthwhile and vital for new technologies such as PMF. In particular, partners said that they felt that this is something that should be done more in future projects:

"It has great integrity and people have confidence in the results because of that. I think we can certainly use that as you say. We did do that through the public exhibitions and I think that's really helped us have meaningful discussions at those exhibitions rather than people feel like they're taking the party line from a group of people who are invested in the development of a particular technology. They saw the impact from those other groups and that was fantastically valuable to the project and continues to be." (S&T partner)

When a more immersive exhibition was suggested, one senior scientist commented: *"Next project, we need to budget for that." (S&T partner)*

"this public engagement it's absolutely necessary but it's sort of a never ending story. I think we should be able to find somehow tools to educate the new generations earlier." (S&T partner)

In summary, the S&T partners recognised some limitations in engaging stakeholders in dialogue around novel technologies without prior contextual awareness. However, partners recognised that the research had revealed some interesting questions, and in some cases had challenged their preconceptions of the relationship between stakeholders and scientists. The partners also reported that the way that the research had built an authentic foundation around stakeholder values had been hugely helpful for the public engagement and gave scientists the confidence and tools to engage in meaningful dialogue with people who have no prior knowledge of PMF.

0.6 Conclusions

As design researchers and social scientists, we instinctively understand the importance of meaningful engagement when building trust in unfamiliar, or even feared, technologies and products. Through experience we understand that meaningful engagement cannot be built on superficial and ill-considered assumptions about the value to stakeholders. Indeed, we have found that a deeper level of understanding, achieved through a well-resourced, dialogical, and iterative codesign research process, can achieve an authentic narrative based on the lived experiences of those people who will ultimately be impacted by the technologies. Through this chapter we have presented research processes and particularly co-design ones, to demonstrate the value and impacts of participating in the process, for scientists and stakeholders such as patients, healthcare professionals, the wider public and S&T partners.

Therefore, our main finding is that design research and social science can provide the research methods and co-design tools to build proximity between developers of S&T Innovations, such as PMF technologies, and wider audiences so that they can engage in meaningful dialogue. An iterative process allows for a deep and meaningful narrative to be developed that tells the story of a novel technology from multiple perspectives and allows the voices and concerns of diverse stakeholders to be heard. This approach builds an authenticity which reaches beyond the assumptions of technology developers and enables meaningful dialogue with general audiences.

The approach has the potential to fundamentally shift how the sciences communicate with specific and general audiences, mitigating the damage that has previously been caused by avoidance, and the consequential impact of sensationalised media. However, deep and meaningful iterative approaches to stakeholder and public engagement must be prioritised in novel technology development projects. There is no short-cut to public engagement of this type; if deep and meaningful engagement research around the value of technologies to stakeholders such as patients and healthcare professionals is to be achieved, project coordinators need to resource and invest in this approach and bring in people with appropriate expertise in these methods.

One shortcoming of the research was that we were unable to engage with more sceptical members of the public who may not immediately appreciate the direct value of the technology on human or animal health. This was due to lockdown restrictions which prevented the planned 'pop-up' events. This could be a next step for PMF public engagement as S&T partners in the Pharma Factory project also expressed an interest in engaging more widely to build dialogue with general audiences, to raise awareness and literacy in PMF, and discover more about their concerns and questions. Recognising the value of sensory and experiential public engagements, S&T partners were also keen to trial more experiential engagements in future projects, utilising interaction design expertise to further explore PMF safety with the public. The PMF community also hope to make the icon language developed during the project a 'standard' visual language in the field, led by Professor Julian Ma.

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