delivery[21]. For example, Gehrke's recent study[9] on the public's understanding of nanotechnology and tolerance for different regulatory responses puts forward a compelling case that the public's distrust of companies and governments means they are more favourably predisposed to labelling as a form of regulation, rather than traditional 'top-down' regulation. Thus, there may be reasons to explore labelling as a first 'light-touch' approach to nanotechnology regulation, while the science matures sufficiently to inform the development of more traditional methods. ❐

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On the elusive nature of the public

Discussions on agricultural nanotechnology are pervaded with conflicting accounts of public opinion. A pragmatist concept may help to explain why this is so difficult to identify.

Koen Beumer

It is widely recognized that the public plays a key role in the success or failure of nanotechnology. This is particularly pertinent in the case of agricultural nanotechnologies, which may offer tremendous public benefits by contributing to global food security. However, nanotechnologies in the field of food and agriculture are also more prone to public concerns when compared to fields such as energy, construction or computing[1,2].

Recent corporate behaviour also confirms the important role of the public. Even though numerous food and agriculture applications have been developed, ranging from the improvement of feeding efficiency in livestock to the controlled release of chemicals to crops[3,4], the fear of a public backlash is reportedly withholding efforts at commercialization[5,6]. With the shadow of genetically modified crops looming large[7], fear of the fearful public seems to challenge technological progress — a phenomenon philosopher Arie Rip called "nanophobia-phobia"[8].

While the importance of public opinion is clear, it is far less clear who this public actually is. In discussions on nanotechnology, the public is alternatively described as knowledgeable and ignorant, enthusiastic and fearful, engaging and uninterested[9]. Even public engagement activities, which are explicitly designed to give the public a voice, have not been immune to such contradictory accounts. Participating members of the public have been found to resist and transform the roles and identities ascribed to them[10]. In some cases, the public opinion that was identified in public engagement activities has even been directly contested by groups with opposing views, who claim to represent 'the real public'[11].

The public is thus an elusive category that is exceedingly difficult to pin down[12]. This poses significant challenges to practising nanoscientists, for whom this lack of clarity creates uncertainty over the general perception of their work. Conflicting accounts of the public are unlikely to disappear, however.

I argue that the elusiveness of the public can best be understood by defining the public as a societal group that emerges in relation to the indirect consequences of technological developments. The challenge then is not to identify a singular public opinion once and for all, but rather to identify multiple publics in an ongoing process, keeping in mind that in fact the elusive nature of the public is an essential feature of democratic governance.

Elusive publics

The discussion about nanotechnology in India is a case in point. India is actively investing in nanotechnology research and has a rural population of almost 900 million people[13,14]. Both nanoscientists and politicians have subsequently argued that nanotechnology efforts should be directed towards agricultural applications, especially considering that "a significant portion of our population [is] dependent on agriculture"[15] — that is, because it benefits the public.

However, even though the public is central to these efforts, contradictory accounts are given about who the public is and how it perceives nanotechnology. Concerning public awareness, for example, some scientists claim there is "massive public interest in India in this new technology"[16], whereas others claim that the public is barely aware of nanotechnology at all and at most may be familiar with the term 'nano' through the Tata Nano (a small car). When it comes to public opinion, some argue "the term nano has elicited … cases of unreasoned fear by the general public"[17], whereas others expect the public to unconditionally accept nanotechnology given that it is supported by well-respected leaders such as the late President Abdul Kalam.

Also, the public's role in the development of nanotechnologies is contested. Some represent the public as an actor whose reluctance to accept nanotechnologies will be overcome when accurate information is provided about the technology's benefits. This portrays the public as laity or consumers[18]: a rather passive actor with no role to play in technology development. In contrast, others — such as former Vice-President Hamid Ansari — depict the public as an actor with acute knowledge about their own needs, whose engagement with nanoscientists can help to ensure that technological developments are responsive to public needs[15]. This portrays the public as a stakeholder or citizen, who has the right and the ability to highlight the potential impacts and interests involved[18].

The public is hence simultaneously portrayed as active and passive, aware and ignorant, supportive and fearful. It appears that the public perception, as one commentator wrote, is both "elusive and open to multiple constructions"[19].

Defining the public

Wickson, Delgado and Kjølberg[18] earlier argued that this heterogeneity in how "the public as a whole" can be represented should not be overlooked. This heterogeneity may be challenging, however, for scientists, governments and companies dedicated to developing nanotechnology applications in food and agriculture, as uncertainty over public views may pose significant risks to investments. From the perspective of practising nanoscientists, especially in the field of agriculture, a singular and stable understanding of the public may offer the greatest certainty in deciding what technological solutions to pursue.

Instead of attempting to pin down the public perception once and for all, I argue that elusiveness can be better understood as a fundamental characteristic of the public. The pragmatist conceptualization of the public offers a particularly helpful perspective. This theoretical tradition, which can be traced back to American philosopher John Dewey, defines the public in relation to specific issues raised by technologies. The public, Dewey writes, "consists of all those that are affected by the indirect consequences of transactions to such an extent that it is deemed necessary to have those consequences systematically cared for"[20].

At the core of this concept lies a distinction between the public and the private: when a transaction between two actors has consequences for those actors alone, then this is considered a private act; when the consequences of this transaction go beyond those directly involved in the transaction, then these consequences are considered a public affair. For example, when a university licenses a technology to a company that subsequently causes environmental damage, then this transaction has consequences that go beyond the university and the company in question. According to Dewey, the public literally does not exist until such indirect consequences "calls it into being".

The public further comes into being only when the indirect consequences of technologies are not "sufficiently cared for", in Dewey's terms. Hence, there is no public when technologies have consequences that existing institutions are fully capable of handling, for example when adequate regulations for environmental risks are in place. As one scholar wrote: "no issue, no public"[21]. Only when existing institutions fail to adequately care for the indirect consequences of technologies do publics come into being.

Following this definition of the public, the elusive nature of the public can be seen in a different light. For one, rather than being concerned with the opinion of 'the public in general' — for example comprising all inhabitants of a country — multiple publics may exist simultaneously, each defined by a shared way in which they are affected by the technology. Seen from this perspective, the different accounts of the public in India may reflect different ways that groups of citizens are affected by nanotechnologies.

Furthermore, this definition highlights that public perceptions should be understood in relation to existing institutional capacities to care for the consequences of technologies. This is in line with earlier findings that public views are not only informed by people's understanding of the technology, but also by their trust in existing institutions[22–24]. Public concerns about agricultural nanotechnologies can hence be understood as indications for the perceived shortcomings of existing institutional arrangements to deal with new technological developments.

Implications

The pragmatist concept of the public offers concrete guidelines for action. For one, the pragmatist perspective shifts the priority from studying the views on agricultural nanotechnology of "the public in general", to identifying those groups for whom nanotechnology applications create new issues that are not yet adequately cared for.

In practice, this calls for sustained attempts at identifying the possible indirect consequences of technologies — consequences that call publics into being. This may require actively engaging with various societal groups, particularly those groups of citizens that would first experience possible indirect consequences. This may also require collaboration with the social sciences, where various methods have been developed both for engaging with publics and for investigating the potential indirect consequences of technological developments.

Secondly, the pragmatist concept suggests that attempts to identify the public are inevitably partial and temporary. The indirect consequences of new technologies may not all appear at once, nor will they all be visible from the onset. The publics that are called into being can therefore change over time, as new consequences become visible. The identification of publics, in the words of Dewey, is an ongoing project that requires continuous vigilance and engagement[16]. Previous attempts to give publics a voice concerning agricultural nanotechnology should, therefore, be seen as partial elements of an ongoing process of calling publics into being.

Embrace the public

When understanding the public as an emergent category that is defined in relation to issues raised by new technological developments, the heterogeneity of the public directly follows from the various consequences that agricultural nanotechnologies may have on different societal groups.

Reversely, the absence of publics may indicate that the indirect consequences of agricultural nanotechnologies are sufficiently cared for. This is only the case, however, under the condition that mechanisms are in place for the timely identification and care for those consequences. The pragmatist concept of the public thus first and foremost urges us to create favourable conditions for publics to emerge, for example by collaborating with social scientists and by directly engaging with the societal groups that would first experience possible indirect consequences. Rather than fearing the fearful public, nanoscientists should always be on the lookout for new publics to emerge. ❒

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How nanocarriers delivering cargos in plants can change the GMO landscape

Genetically modified organisms as foods are a globally contested topic. What dictates the regulatory oversight of genetically modified crops could be redefined by advances in nanotechnology and genome editing.

Markita P. Landry and Neena Mitter

Few issues are as polarizing as genetically modified organisms (GMOs) as foods, with substantial variability in what constitutes a GMO across different countries. In the advent of new technologies such as genome editing, the landscape of how plant genetic manipulation is accomplished is bound to shift both regulatory purview and public acceptance of GMOs. Today, the development of a genetically modified (GM) crop is estimated to take 13 years of research and development at a cost of US$136 million[1,2], whereby the regulatory definition of a GM crop is defined by the incorporation of foreign DNA into the plant host genome or the use of a bacterial pathogen, features of plant genetic manipulation that are difficult to avoid with current plant transformation technologies. The emerging world of nanotechnology in agriculture has the potential to change the existing paradigm of plant genetic modification by leveraging nanocarriers as shifters of the current GMO landscape. Partnership of nanotechnology and biology has already started to change the contours of this new landscape and to challenge existing legislations.

Plant transformation standards

Genetic engineering of plants is increasingly important to generate pathogen-resistant and high-yielding crops amid a growing population and changing global climate. The workflow for generating a genetically engineered plant varietal involves delivery of DNA to plants, followed by selection of successful transformants and regeneration of the GM progeny. The former of the two, biomolecule delivery, is uniquely challenging to accomplish in plants, due to the presence of a rigid and multilayered cell wall. Consequently, conventional approaches for biomolecule delivery to most cells, for which the dominant barrier is the lipid membrane, cannot be used for delivery in plants. Two predominant methods for biomolecule delivery in plants are *Agrobacterium* and biolistic delivery, the former of which is only amenable for delivery of DNA targeting nuclear transformations. *Agrobacterium*-mediated delivery is tractable for a limited range of plant species, can only target the nuclear genome, and results in random DNA integration and constitutive expression, which may disrupt endogenous plant genes and limits temporal control over transgene expression. Biolistic delivery of DNA using gold particles involves a high-pressure gene gun and relies on physical disruption of the plant cell wall and membranes, which can yield tissue damage and multiple transgene insertions into random portions of the plant genome. With both delivery modes, integration of transgenic DNA into the plant genome triggers GMO labelling of the transformed plant, if it is to be sold as a consumable.

Nanocarriers for GM crops

Despite delivery limitations, there are success stories in the generation of GM crops. GM cotton, corn, soybean, canola and sorghum are examples of food and feed crops adding value to the US$5 trillion global agribusiness industry[3]. The economic gains from GM cotton in India[4], GM canola in Australia[5] and recent acceptance of Golden Rice in Bangladesh[6] highlight need-based considerations to meet the challenges of food and nutritional security. However, generation of such crops with current tools, as described above, is laborious and largely subject to GM regulatory purview. Approaches that enable finer control over biomolecule delivery to plants with unassisted internalization through the cell wall could challenge how GM crops are both produced and subsequently regulated. Compared with the approximately 500 nm size exclusion limit of the cell membrane, the plant cell wall excludes particles larger than approximately 5–20 nm (ref. 7). Nanomaterials, defined as having at least one dimension measuring under 100 nm, thus present a unique opportunity for biomolecule delivery to plants. While nanomaterials have been studied for gene delivery into animal cells, their potential for plant systems is a more recent undertaking. In a pioneering study, mesoporous silica nanoparticles