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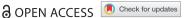A. Wendy Russell, Aleksandra Stelmach, Sarah Hartley, Lucy Carter & Sujatha Raman

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Opening up, closing down, or leaving ajar? How applications are used in engaging with publics about gene drive

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ABSTRACT

Public engagement and responsible innovation are strongly emphasised in gene drive research, together with the goal of addressing societal challenges, notably, malaria and environmental conservation. We aim to explore whether public engagement is used to 'open up' or 'close down' opportunities to shape gene drive research. Drawing on interviews with gene drive developers and stakeholders, we investigate how the public communication of gene drive is conceived. We find that traditional closing-down tendencies remain, but that there are new and encouraging opening-up approaches. Consistent with responsible innovation thinking, these frame gene drive as multifaceted, context-dependent and requiring deeper deliberation. We also identify a third 'leaving ajar' approach that seeks to engage with and respond to local communities and modify technological applications to be more acceptable. Innovation system constraints may well temper current aspirations to open up; framing public conversations around understandings of public good could offer a way forward.

Introduction

Gene drive is emerging as a field of new technological possibilities with a strong emphasis on public engagement (Ledingham and Hartley 2021). However, previous experience shows that examples of public engagement and deliberation playing a substantive role in the responsible development and governance of new technologies, remain elusive. This raises the question of whether gene drive is just a continuation of this trend, and therefore similarly problematic, or if there is something genuinely different about public engagement in this novel context. We aim to explore this question via empirical research investigating strategies used to communicate and engage with publics around gene drive.

Interest in consulting with publics and stakeholders has characterised the field of gene drive since its inception, even as scientists first began to identify potential technological applications of their research (e.g. Benedict et al. 2008; Marshall and Taylor 2009; Adelman et al. 2017; Min et al. 2017). As these applications gathered momentum, an influential report by the National Academies of Sciences, Engineering, and Medicine (NASEM 2016) suggested that the outcomes of engagement may be as crucial as scientific outcomes to the development of gene drive. Engagement with local communities in regions where field trials are envisaged is now an established part of gene drive research (e.g. Hartley et al. 2019). In this paper, we examine if such developments represent an 'opening up' of public communication of gene drive to the type of wide-ranging appraisal of issues that scholars of responsible innovation and public engagement have been calling for (Stirling 2008). In the words of Stirling and colleagues (Stirling, Hayes, and Delborne 2018, 44), is gene drive open to questions of "'which way?', 'who says?' and 'why?'"?

Drawing on empirical and normative analysis, public engagement scholars have shown why engagement processes must allow for an 'opening up' of the problem at stake and of solutions offered by emerging technologies (Marris and Rose 2010; Stirling 2008; Stirling, Hayes, and Delborne 2018). Openness is important for both democratic reasons (people being able to shape matters that affect them) and epistemic reasons (people being able to contribute knowledge that is required to make better decisions about research and its governance) (Stirling, Hayes, and Delborne 2018). When emerging technologies claim to address grand societal challenges, it should be possible to scrutinise how problems and solutions are framed, and consider alternative solutions and different possible pathways for science (Nuffield Council of Bioethics 2012). Processes of public communication and engagement must make this kind of open scrutiny possible.

However, research shows that, in practice, engagement processes are often structured in ways that 'close down' questions about the wider context of emerging technologies, and get locked into a narrow orientation towards public acceptance of a pre-determined technological pathway (Delgado, Kjølberg, and Wickson 2011; Marks and Russell 2015; Mohr and Raman 2012; Wynne 2006). What we know less about, however, is whether and how centering public engagement around specific applications to 'grand societal challenges' makes a difference to this pattern, particularly when applications are rooted in a non-profit 'public good' ethos. Brooks and colleagues' (2009) work on biofortification for malnutrition, suggests that despite their morally compelling goals, such technological promises still need to be scrutinised with the opportunity to consider different possible pathways. The specific aim of this paper is therefore to explore how potential gene drive applications – e.g. those targeting malaria eradication or invasive species control for conservation – are being used in public communication. We ask if such applications foster such an opening up of issues to be discussed, or indeed, if strategies for communication follow the familiar tendency to 'close down'.

The capacity of research on emerging technologies to promote public good is shaped in part by the public communication of science (Roberson, Leach, and Raman 2021). How research aspirations and agendas are communicated is critical for making it possible to 'open up' issues that need discussion (see also Grunwald 2017). Hence, we focus our empirical work on gene drive stakeholder understandings of the nature and purpose of communicating with publics and, in particular, their use of applications to structure their public communication and to achieve their communication goals. To date, although

there is a considerable body of work by social scientists including papers co-authored with gene drive scientists (e.g. Backus and Delborne 2019; Hartley et al. 2019; Ledingham and Hartley 2021; Schairer et al. 2019; Kokotovich et al. 2020; Special Issue of JRI 2018 on 'Roadmap to Gene Drive'), research into how members ('stakeholders') of this multidisciplinary community think about the goals and strategies of public engagement is lacking. While the research and practice of public engagement on gene drive are becoming established (e.g. Hartley et al. 2019; Schairer et al. 2019), there is little empirical work on how those involved in engaging with publics understand and communicate about gene drive issues. We fill this gap through qualitative interviews with key stakeholders drawn from across the gene drive domain to include: gene drive scientists and developers; communicators; social scientists and ethicists; and representatives of civil society/non-government organisations (NGOs).

The paper is structured as follows. First, we elaborate on the reasons why gene drive is worth considering as a potential departure from the familiar narrowing of public engagement around emerging technologies. We then turn to details of our research methods before going on to present the results from interviews. We explore the contribution of these findings to social science research on public engagement, responsible innovation and gene drive in the Discussion before concluding with reflections on the implications for the future of gene drive.

Could gene drive be open to 'opening up' public engagement?

There are good reasons to ask if gene drive marks a departure from conventionally closed engagement strategies oriented towards (premature) public acceptance of a pre-given technological solution to a societal challenge. We outline four before considering reasons for caution.

First, gene drive research is emerging at a time of wider interest in responsible innovation (Stilgoe, Owen, and Macnaghten 2013a). Since the late 1990s, science policy institutions have promoted public engagement as a solution to high-profile instances of controversy and opposition (Irwin 2006; Nerlich et al. 2018). Genetically modified (GM) organisms have featured heavily in this evolution, with subsequent research efforts in nanotechnology attending to engagement under the rubric of learning lessons from the biotechnology experience (Kearnes et al. 2006; Barben et al. 2008). Responsible innovation has since been institutionalised as a strand of work within research centres devoted to synthetic biology, notably in the UK (Balmer et al. 2015; Pansera et al. 2020). Given this wide experience in initiatives to 'make science public' (Nerlich et al. 2018), it is not unreasonable to expect that scientists and science organisations might be starting to take a more open view of science/public engagement beyond simple acceptance.

Second, ethics and public engagement in gene drive do not appear to be marginal issues relegated to social scientists as in previous cases (Viseu 2015). Social scientists are playing significant roles as collaborators and/or interlocutors in the gene drive community (e.g. see Delborne, Kokotovich, and Lunshof 2020; Hartley et al. 2019; Long et al. 2020). The recent 'Roadmap to Gene Drive' special issue of the *Journal of Responsible Innovation* demonstrates that broad-ranging conversations are happening between biophysical and social scientists well-versed in the case for 'opening up'. For example, one

scientist argues that gene drive can transform the scientific enterprise altogether by embedding open assessment of early-stage ideas prior to experiments, and redesigning proposed interventions based on feedback (Esvelt 2016).

Third, the very nature of gene drive and its potential applications beyond the laboratory is provoking new ways of thinking about engagement, at least on the part of some in the gene drive community. As Evans and Palmer (2018) have shown, the Committee on Gene Drive Research informing the landmark National Academies report (NASEM 2016) underlined intentional spread and potential irreversibility of environmental effects as attributes distinctive to gene drive. Similarly, in the journal literature, one team describes gene drive as an ecological tool or 'ecotechnology' (Najjar et al. 2017), raising the prospect that communities will reject it for this reason, while also calling attention to the unique knowledge that they can contribute to design and responsible governance. The more novel notion of public engagement as 'knowledge engagement' (Hartley et al. 2019) therefore features together with familiar goals of public acceptance in this work (Ledingham and Hartley 2021). Anticipation of complexity, a need to examine assumptions of safety and controllability of gene drives, and acknowledgement of ecological uncertainty arising from the prospect of escape and boundary-crossing are being openly discussed (e.g. Baltzegar et al. 2017; Backus and Delborne 2019). In sum, there is a sense in some of the literature authored by scientists that public engagement is needed not only to manage the risk of resistance to deployment, but also to collectively figure out ways for the technology to work.

Fourth, gene drive science has come to be defined in terms of grand challenge applications (e.g. Min et al. 2017) in ways that are somewhat unique. The focus on application to malaria so dominates the discussion of gene drive that it is difficult to find explanations or images of the concept that do not feature mosquitoes. While other emerging technology fields have highlighted particular applications in response to key challenges in food or energy futures (e.g. bio: nitrogen-fixing wheat for food security; nano: batteries for renewable energy), these have tended to play a promissory role, exemplifying a diverse array of possibilities following from a 'new' field of science (Doubleday 2007; Petersen and Krisjansen 2015). By contrast, gene drive science more directly focuses on developing proof-of-concept for specific challenges such as malarial control and invasive species control in the here-and-now. In most prior cases of emerging science, future applications were expected to be delivered through commercial mechanisms. Gene drive, by contrast, has been associated with 'public good science', with innovation configurations such as public-private partnerships and philanthropy-funded non-profits featuring strongly. By avoiding controversies over commercial conflicts of interest that plagued previous generations of GM, it is possible that gene drive is more able to promote deliberation of issues that need public discussion from an open standpoint.

In sum, these observations raise the possibility that commitment to public engagement and the focus on public good applications may constitute a distinctively open stance in gene drive development. Nonetheless, there are reasons to give us pause. First, concerns about commercial interests are not entirely irrelevant. The prospect of profit-making uses arises most notably in the context of applications of gene drive to agricultural pest control (Scott et al. 2018; Meghani and Boete 2018). NGO critics argue that gene drive for malaria is a 'Trojan horse' – a glittering disguise used to smuggle in subsequent for-profit applications (Mentz-Lagrange and Sirinathsinghji

2020). Second, social science research provides a note of caution as there is evidence in gene drive of public engagement being translated into a narrow public acceptance model of seeking 'social licence' for a pre-given technological application (Delborne, Kokotovich, and Lunshof 2020), although the authors go on to identify counter-examples that signal more optimism. Ledingham and Hartley (2021) similarly note that ambitions for new forms of engagement in gene drive research often 'slip' back to reductive framings which close down the range of voices and issues to be heard. For these reasons, we propose to investigate public engagement around gene drive in more depth.

Research questions and methods

We conducted 30 qualitative interviews with stakeholders in the UK, US and Australia, all countries with prominent research projects in gene drive. Permission to carry out this work was granted by the Research Ethics Committee at the University of Exeter Business School. We used a purposive sampling strategy to recruit different types of participants, such as gene drive developers/life scientists, social scientists, ethicists, journalists/broadcasters, science communicators, as well as members of NGOs and industry. It should be noted that not all stakeholders were necessarily engaged in public communication around gene drive to the same extent; this could be partly due to differences between the three countries in terms of progress on gene drive applications.

The interviews followed a structured script, but also allowed additional and clarifying questions, and provided participants with an opportunity to discuss issues they deemed important. The interviews lasted 30–60 minutes, and were conducted using video-conferencing platforms (Zoom, Microsoft Teams and Skype). The interviews were digitally recorded, transcribed by a professional transcriber and anonymised. We then analysed the data to explore how various stakeholders talk about the use of gene drive applications in engagement, and to see if and how they display tendencies to close down or allow an opening up of issues.

The primary focus of the interviews was on strategies used by stakeholders to communicate with non-science audiences about gene drive. This was informed by the aim of the project which was developed in response to the Wellcome Trust funding call for research on communicating science in the case of gene drive. However, as is common in qualitative research, we were alert to the emergence of other relevant themes in the interviews and followed them up as appropriate. In this paper, we focus on interviewees' references to public engagement, or their discussion of the kind of two-way communication that typifies engagement. Given that interview questions did not explicitly ask about engagement or applications, references to public engagement and specific applications that emerged in interviews were thus relatively unsolicited and therefore interesting in their own right. We believe these references, which were numerous across stakeholder types, reflect our observations above about the importance of public engagement and the focus on applications as a communication strategy. We analysed these references to gain further insights into this strategy, drawing on the following research questions to shape the data analysis discussed in this paper. *How are people using applications in their communication, particularly in relation to engagement? Are applications being used to close down or open up public deliberation about gene drive?* During our analysis,

we also became interested in the question: *What is the relationship between applications, public engagement approaches and innovation contexts?*

Interview transcripts were coded using Dedoose (version 7), using the codes *applications*, *goals* and *decisions* to explore references to applications in interviewees' communication about gene drive, and how these references connected with goals and decisions. Transcripts were also analysed for the code *GM* because they were explicitly asked about the connection between gene drive and GM (genetic modification) communication, and because this connection appeared to underpin their use of applications. Extracts were then exported to tables for each code and themed according to whether they reflected closed or open communication. A third pragmatic category, which we titled 'leaving ajar' and which we explore in more detail in the next section, emerged from this analysis.

Approaches to using applications in gene drive communication

Our data reveals three high-level approaches that characterise different ways in which applications are used in gene drive communication: closing down, opening up and an intermediate, pragmatic category we call 'leaving ajar'. We explore each of these approaches using illustrative interview quotes.

Closing down

In line with an earlier generation of public engagement around emerging technologies, our data suggest that some developers and communicators engage primarily to convince the public about the promise of gene drive, and to gain public acceptance and trust for getting experiments through to trials and application. In this section, we examine evidence from interviews of this 'closing down' model of public communication. The promise of novel applications to solve grand challenges in global health features heavily, offering a morally compelling rationale for gene drive. Linked to this is a sense of needing to distance public communication around gene drive from associations with GMOs and GM agriculture in particular.

Developers and communicators made explicit reference to (others) using the application of gene drive in control of malaria to 'sell' gene drive technology. For example:

> … mosquitoes are the poster boy, if you like, of the gene drives, at this stage. Mosquitoes are bad, that's what people are using to sell it … . (Aus developer)

References to global health applications were accompanied by a reminder of the costs of not acting and gene drive advocates appealed explicitly to this moral argument for gene drive research:

> So that's [malaria mosquitoes] the best application and the easiest to justify, in my view, because there aren't obvious alternatives and the need is still so pressing. (UK developer)

> … in the course of this conversation that we've been having malaria has killed approximately 30 children under the age of five and no one with a heart can think about that and then think about how their mothers must be feeling right now and not want to do something about it. (US developer)

Some participants suggested that a focus on global health can help make gene drive more publicly acceptable, whereas applications in agriculture and food are anticipated to be more contentious:

> Maybe when it comes to agricultural uses this is probably not being discussed as much, because I think that wouldn't immediately draw the same level of support in something like malaria. So I think almost always malaria is there as sort of a headline case. (UK developer)

Some (though by no means all) NGOs expressed concern about how the promise of gene drive applications has been used in public communication.

> … a lot of what is happening in the debate is highly manipulative in terms of getting the minds to try to only see the benefits and to not see the risks and the negative impacts … 'It's to eradicate malaria' – the mind has already been sent down a certain route. (UK NGO)

The focus on a specific challenge to make a compelling case for gene drive can close down options for public debate by presenting gene drive as the best or only solution. In this respect, gene drive communication shows some similarities with the earlier history of public communication about emerging biotechnologies where the focus on a specific pathway obscured attention to uncertainties and alternative options (Stirling 2008; Nuffield Council on Bioethics 2012).

Such 'closing down' strategies (emphasising the severity and urgency of the problem, presenting gene drive as the best solution, avoiding more contentious applications) are underpinned by lessons learned from public opposition to GM crops. Many participants, from all countries and a range of interviewee types, referred to the public's dislike of GM and some, again from all countries and a range of types, suggested that this is based on ignorance of the costs and benefits, low scientific literacy, and/or lack of trust in expert opinion:

> the public just is not very scientifically literate … it just gets conflated because the general public, it just doesn't know enough about the technology and so it all kind of blends into one thing. (US communicator)

> … there seems to be a general distrust or not really respecting the expert opinion … . (Aus developer)

Some UK participants felt that GM has too much 'baggage' and should be avoided in gene drive communication:

> I try not to use the term 'genetically modified' as much as possible. (UK developer)

> But in our project, we try never to use the word GMO. (UK communicator)

Overall, using applications to close down gene drive research trajectories was especially evident in relation to malaria control technologies, and in particular, amongst developers and communicators in the UK and the US. However, our data suggests that other approaches to public communication are also evident.

Opening up (and out)

Our data also suggests evidence of an 'opening up' approach towards public communication about gene drive, where talk of applications might be associated with more open

discussions. In this approach, gene drive is seen as multifaceted, with some developers and communicators seeking to engage on a broader range of issues than anticipated benefits or risks alone. Social scientists are, unsurprisingly, part of these efforts to 'open up' discussion of gene drive, but they are by no means the only stakeholder type represented here. We find evidence of a spectrum of stakeholders including developers and communicators taking an open stance, particularly in the context of gene drive applications for conservation. We also see examples of what we call an '*opening out*', i.e. an interest in looking beyond the technology per se, and considering bigger questions such as whether the technology should be developed at all. Many of the quotes that follow illustrate a willingness to engage in contextual discussions of the application of gene drive on a case-by-case basis.

For example, one participant noted that people might reasonably make different judgments about deployment depending on various conditions:

> So there's a lot of different dimensions that will make each organism very different from the next and whether it's acceptable, desirable, viable could be a completely different answer for one and the next … . (US communicator)

By contrast with the 'closing down' approach, we see in our data some evidence of an open approach focusing on engagement with publics not simply to gain their acceptance, but to genuinely ask *whether* the technology should be used for the particular problem:

> Then there is a broader public engagement or a stakeholder engagement issue … … whereas they [the public] might have a need to be addressed and then they need to be agreeable that this is a good approach to be taking. (UK developer)

> Have the communication around it [gene drive] before there's any pressure on whether we do or don't [use it]. (Aus industry)

> From the community perspective it might go either way. They might say we want it, they might say we don't want it but at least they have chosen something that applies to them. (US communicator)

The point raised by the Australian industry stakeholder above suggests an acknowledgement of the need to engage early in the process before momentum builds around a technology. In this open approach, which is more evident in the case of applications for conservation, gene drive is just one possibility among a range of alternative solutions:

> Certainly in Australia we have a large invasive pest problem, many species are damaging the environment, so CSIRO has a large group of people working on invasive pest management and they can see gene drive as being potentially one of the technologies that will be useful. (Aus developer)

Another developer suggested that the very development of a gene drive for conservation is likely to depend on how communities react.

> … we're doing public engagement with communities to make sure that they will support us in terms of releasing into their area and it's just one of all of the different factors that we're collecting data on which will inform our final decision as to whether we even bother to develop a drive, or where we will develop that drive or how. (Aus developer)

While gene drive research has been many years in the making, some scientists are beginning to see public engagement as a productive part of ongoing scientific activity

in which the viability of specific technological applications is being explored. In principle, early engagement may have a chance to influence outcomes before precious time and resources become 'locked-into' a particular technology in a particular setting. The following quote illuminates this point and suggests that while building public trust may still be part of an open approach to communication, trust is seen as an outcome of open engagement rather than a strategy to build support for a pre-given technology.

> We're talking to the public about gene drives before we've developed the technology and we've never done that before so we can talk to the public without an immediate perception from them that we have a vested interest … .. it's just a learning process that we've had from doing it badly, whatever technology it is, doing the public engagement poorly in the past … it's making the public conversations much easier because I can go in and say 'I'm not convinced yet', and in complete honesty I can go in and say that and I say, 'And I don't have a technology yet'. (Aus developer)

Some participants saw conservation applications as being ideal for opening out discussion of gene drive as publics are culturally attuned to both the history of havoc caused by invasive species and the potential for new environmental interventions (like gene drive) to go wrong:

> I do think this history, with the introduction of rabbits and … then the introduction of the Calici virus [a rabbit virus introduced to control pest rabbits] and so on and so on … it gives something that the average person in the street in Australia is highly familiar with to be able to structure an explanation [about gene drive]. (Aus social scientist)

The open approach to the use of applications for communication also echoed more open views on GM debates. A broad range of stakeholders offered more complex understanding of and respect for diverse public perceptions of GM. Some drew on their own or others' research on public reactions to GM, or made insightful comparisons between the GM debate and discussion of gene drive, for example:

> I would not be surprised if gene drive became the lightning rod for these issues about the loss around nature, in the same way that the early GM discussion was a lightning rod for discussions about the commercialisation and internationalisation of the food chain. (UK policy maker)

Some NGOs who were not themselves critical of gene drive *per se*, noted reasons why the public might reasonably understand the mode of intervening in nature very differently from biophysical scientists, and why their views would need to be given some weight.

> So obviously other people have other concerns and some of them are huge. So people have philosophical concerns about whether it's appropriate to be messing around in the genetics of other species … One has to really respect, I think, other people's philosophical and spiritual beliefs. (US NGO)

Some developers put forward the possibility that publics would (or should) be *more* concerned about gene drive because of its function in spreading through populations and its potential irreversibility:

> So my attitude is always, look, GMOs and plants have been very successful, very safe, they've certainly decreased chemical inputs in a lot of situations, there are many environmental benefits that have flown from those, that have come from those and not much evidence

> for harm … but then I also say, look, with gene drives, … you have to be more cautious 'cause you are releasing something that may be difficult to call back. (Aus developer)

One social scientist called for recognising the historical context of gene drive to learn about how to better communicate and open up the debate:

> … it's useful to place this particular technology in the broader history of biotechnology, so that we understand where the technology comes from, we understand its limitations, how it builds on existing forms of technical practice … I think it's useful to have a historical perspective so that you understand what are the things that take place over time and what are the things that don't happen so easily, and hopefully the debate can evolve. (UK social scientist)

These more sophisticated and open understandings of the GM debates came from all three countries, but somewhat more from Australia. As expected, such views of GM came more from social scientists and NGOs than from gene drive developers. In general, communicators seemed to share similar views to developers (some of these interviewees worked for developers' organisations). In sum, our data shows evidence of opening-up thinking as well as the closing-down discussed earlier. However, we find that these two polar opposites do not fully capture possible stances to public communication of gene drive.

Leaving ajar

We find evidence for a third position that we call 'leaving ajar', where communication about gene drive applications is responsive to public views, but with a pragmatic focus on creating the conditions that might allow the technology to be successfully deployed. In this approach, participants used applications to emphasise problems and problem contexts. In common with the 'closing down' strategy of communication, this approach was similarly oriented towards public acceptance of gene drive by attending to its uses and benefits. However, by contrast with the tendency to close down, there was acknowledgement of the need to engage with communities about problems rather than merely seeking their responses to the technology, thus demonstrating similarities with an opening-up stance. Indeed, some stakeholders expressed both types of views, i.e. leaving ajar the question of how gene drive is to be developed while also remaining open to the possibility of bypassing the technology altogether depending on the outcomes of public engagement. In this respect, communication strategies were shaped in part by what gene drive developers or communicators discovered about community priorities early in the process of engagement.

Participants sought to engage with publics on the problem at stake and put forward a case for gene drive solutions in this context:

> … trying to communicate not so much the solution but the problem is important, trying to get people to understand why we're doing things, why scientists are working on gene drives. (Aus developer)

The leaving ajar approach to communication was also influenced by experiences with the GM debate, but in a more nuanced way than seen in a closing down stance. Some emphasised the need to be open about the connection between gene drive and GM, regardless of the negative associations:

So while I don't necessarily feel it's something we need to dwell on and emphasise in our communications, I think to say that it's not genetically modifying individuals is a huge mistake because that's fundamentally inaccurate … . (Aus NGO)

… unless you make that link, you're not explaining it properly, so the idea that you can talk about gene drives without talking about GM, … I think that's not helpful. (UK public agency representative)

Some also emphasised the non-profit nature of gene drive applications, often contrasting these with previous GM applications in agriculture, and anticipating that this might work in favour of the technology:

The for-profit thing is huge, right. … there's a number of different social science studies that show that people just trust biotech less if it's developed by a big for-profit corporation relative to a non-profit. (US developer)

The non-profit, 'public good' aspect was understood by some to be intrinsic to how gene drive works:

… [we] try and explain why we're doing it, what the applied outcome of the work ultimately might be. I think that's probably made a bit easier in the gene drive space, because most of the work and most of the application of gene drive seems to be more in the public good kind of space … It's hard to imagine a commercial scenario that would make a company like Bayer, for example, really invest in gene drive. (Aus developer)

So while the focus is on factors that influence public acceptance of gene drive, this approach reflects much more than an attempt to 'sell' the technology. Rather, public communication is oriented towards securing a social licence or public consent, including in some cases, through activities to build the capacity of publics to make informed decisions:

… in villages where we work, we're starting to do some work with the schools, not yet on gene drive, but we're starting with malaria and mosquitoes, with the idea of bringing the idea of gene drive in the schools through educational material, for them to learn what it is so they can make a decision. (UK communicator)

This approach reflects an aspiration to respond to public input, both in communication and in technology development, particularly at local levels:

… it's not just about going around and getting people to check and sign off on the box that says, yes, you may do this. But it's an engagement; whole communities have to be able to feel comfortable that their views have really been incorporated and are reflected in the values of the technology moving forward. I mean that communication piece is a big part of that but it's a two-way communication, it's not just putting together the best possible description so that people can best understand it, it's also listening to what people's concerns might be and how to incorporate those. (US social scientist)

For some, this focus on social licence and local engagement was associated with a view towards limiting broadly universalist arguments, for example, critiques of gene drive coming from Western countries that do not directly experience malaria.

My biggest concern is that quite frankly malaria is the prime case to go first to and that we have a lot of people who are weighing into the conversation with very strong opinions, not a lot of information, but very strong opinions who have never suffered from malaria, will never suffer from it and so who are influencing the conversation in which direction they want to direct states, and that I find is wrong … . (US communicator)

In sum, the leaving-ajar approach can be distinguished from an opening-up or opening-out stance – where the desirability of using gene drive in a specific context is open to debate – by a fundamental orientation towards deployment. However, it differs from closing-down approaches by the shift in focus from persuading the public to accept the technology, to making the technology more accept*able* in response to public concerns, or in some cases, to creating ways for publics to make informed decisions.

Discussion

This paper set out to examine how potential applications of gene drive are being used to communicate and engage with publics and communities. We aimed to shed light on whether and how the appeal to gene drive applications – such as those targeting malaria or environmental conservation – led to a 'closing down' of public engagement familiar from previous examples of emerging technologies, or indeed, if they made possible an 'opening up' of a complex set of issues for appraisal and deliberation (Stirling 2008).

Given early acknowledgement of the need to engage publics, the rise of substantive collaborations between science and social science, and the aspirations of some scientists to change their practices in response to public input, there were good reasons to expect that gene drive could mark a departure from the closed engagement strategies of previous emerging technologies. The focus on 'public good' applications might also negate concerns about commercial interests which dogged earlier generations of GMOs. However, previous social science work on gene drive and on other cases of morally compelling, public good science provided a note of caution, hence motivating the need for empirical work.

While our results indicate a spectrum of tendencies in the use of applications to communicate with publics about gene drive including the familiar 'closing down' approach, we see developers and other stakeholders speaking in ways that potentially resonate with core ideas of responsible innovation. So while there is language of strategically distancing from links to GMOs and using the prospect of eradicating malaria as an instrument to gain community acceptance, there is considerable evidence of more reflective approaches to public communication. Notably, we find acknowledgement of the value of opening up and 'opening out', as well as of a pragmatic 'leaving ajar' the precise nature of gene drive futures.

An opening up/out is most prominent in Australia in relation to applications of gene drive to conservation goals, particularly the control of (invasive) species introduced by European settlement, but we find similar examples from other countries. This open stance is marked by a potential willingness to engage with different perspectives, to be transparent about links to prior generations of GMOs, to engage about novel characteristics of gene drives and their implications, to acknowledge that gene drive may be only one possible solution, and to countenance modifying the science or, indeed, abandoning gene drive altogether. By contrast, the pragmatic stance that we have described as 'leaving ajar' reflects an aspiration to make gene drive work on the ground. However, this is grounded in an active commitment to community acceptability of the technology as opposed to passive public acceptance of a pre-given option. In this case, making gene drive work means attending to community feedback, modifying interventions in

response to concerns, and trying to be transparent about potentially tricky issues such as the connection with GM. Where the opening up/out ethos potentially reflects the expansive philosophical orientation of responsible innovation as a collective reckoning with the purposes and direction of innovation (Owen et al. 2013), a leaving ajar stance is closer to a practice-oriented philosophy of responsible innovation as a concrete mode of co-designing ways to make a technology work for a specific public.

Table 1 captures these different registers of public communication around gene drive in terms of their implicit goals and strategies (Table 1). The aim of a 'pure' closing-down approach is to 'sell' a technological application of gene drive and to configure a supportive public through strategies such as using morally compelling stories and avoiding 'uncomfortable knowledge' (Rayner 2012) such as links with contentious GMOs. The second stance is, in principle, more open towards such questions as whether or not the technology should be developed or the role of gene drive vis-à-vis other pathways of responding to grand challenges. By contrast, the pragmatic goal of 'leaving ajar' is to make gene drive interventions acceptable by addressing public views, building public capacity for making informed decisions and thereby earning social licence for deployment.

While the Table captures these differences in ideal-typical fashion, in practice, the three approaches should be understood as representing different tendencies that can co-exist and evolve. For example, some stakeholders may be open to approaching gene drive from various perspectives, but it is possible that an underlying commitment to deployment remains. Alternatively, a closed stance could evolve over time into a more open one and a pragmatic stance could likewise co-exist with a more closed approach. We found allegiance to all three approaches across countries and interviewee types, as well as amongst individual interviewees.

In the rest of this section, we elaborate on what these findings contribute to the fields of responsible innovation, public engagement, and social science research on gene drive. First, we observe an evolution of stakeholder attitudes and expectations about public engagement beyond the polar opposites of 'opening up' and 'closing down' (Stirling 2008). This evolution is likely a result of public engagement having become an established field of practice

Table 1. Why and how stakeholders use applications to communicate and engage with different publics.

	Closing down	Opening up	Leaving ajar
Implicit Goal (why)	• Sell GD technology • Build public acceptance • 'Prime' publics for GD release	• Explore GD • Seek public input to decision making • Deliberate about GD as a solution	• Make GD acceptable • Seek social licence • Respond to public concerns
Strategy (How)	• Emphasise the severity and urgency of the challenge • Present GD as the best solution • Tell morally compelling stories • Disassociate with GM & contentious applications	• Engage early • Discuss pros and cons and context, case by case • Go beyond risk, consider broader issues • Learn from the GM debate, understand and respect diverse public reactions • Be open to not using GD	• Engage early • Attend to local communities and their needs • Focus on problems • Compare GD with alternative solutions • Re-frame the GM debate • Emphasise non-profit, public good applications

around emerging technologies. In the case of gene drive, our findings suggest that some gene drive developers are recognising that it is not enough to focus on persuading publics to *accept* their technology; they must rather listen to publics, respond to their concerns and adapt their technology to be more *acceptable*. In this way, a pragmatic ('leaving ajar') approach to engagement can, in principle, lead to innovation in a specific technology domain that responds to public values (as proposed by Fisher 2018), although how such engagements actually unfold in practice is a matter for further inquiry.

Second, some public communication may be underpinned by the notion of seeking 'social licence' for gene drive, but it is not obvious that the concept necessarily signifies a commitment to secure acceptance of a *pre*-determined option as Delborne and colleagues argue (Delborne, Kokotovich, and Lunshof 2020). The term social licence does indeed emerge from the world of mining where it has a narrow meaning, however, this may become modified over time (Dare, Schirmer, and Vanclay 2014) including, for example, in ways signalling responsible innovation aspirations (e.g. Raman and Mohr 2014). In this respect, we do not believe that social licence and responsible innovation are intrinsically opposed. 'Responsible innovation' is also prone to narrow interpretation (e.g. Hartley, Pearce, and Taylor 2017; Ashworth et al. 2019), so much depends on how these terminologies evolve and if they can be redefined in particular circumstances to incorporate broader aspirations. In the case of gene drive, our findings suggest that terms such as social licence may co-exist with a willingness to countenance modifying the design of technologies based on wider input.

Third, evidence of some effort, particularly around conservation applications in Australia, to reflect more openly on how gene drive connects with the spirit of 'broadening out' of technology assessment (Ely, Van Zwanenberg, and Stirling 2014) and responsible innovation called for in the literature (e.g. Stilgoe, Owen, and Macnaghten 2013a; Stirling, Hayes, and Delborne 2018; see also Wodak 2020). Unusually for emerging technology communication, some developers are musing on questions that potentially signal a capacity to open 'up' gene drive and open 'out' from this technological possibility to a broader range of issues. What is the role of gene drive amongst several possible solutions to a grand challenge? Should it be developed at all if there isn't sufficient public backing? In Australia, talking with publics early on, when application trajectories had not been settled, was thought to be valuable. This is despite the fact that upstream engagement is less institutionalised in Australia by comparison with the UK. The emergence of such an aspiration around gene drive may instead be a result of a wider ethos of community engagement around environmental problems and the now-established commitment to integrating social scientists – who have been making the case for public engagement – into emerging technology research in Australia (Carter and Mankad 2021). Cultural awareness of biosecurity issues is also stronger in Australia compared with the UK; it is widely acknowledged that British settlement of the continent resulted in the importation of novel organisms that severely damaged native ecosystems and that continue to pose a threat to agriculture. More speculatively, the eco-technological nature of gene drive (Najjar et al. 2017) may also be prompting an aspiration to open up, though again, we cannot be sure if and how such commitments will translate into practice or, indeed, if new pressures to close down emerge.

Fourth, the legacy of GM controversies is evident in how the gene drive community – across all stakeholder types and stances – is approaching public

communication. There remains a distinct strand of thinking amongst developers and communicators that any association with GM must be quashed in explaining gene drive to the public. However, the emergence of more sophisticated positions is a positive sign for discussions that could open up the broader anticipatory ethos envisaged in responsible innovation (Guston 2008; Stilgoe, Owen, and Macnaghten 2013a). Thus, responses to GM are a classic example of the spectrum of communication strategies from closing-down to opening-up. The choice of strategy seems to be strongly influenced by regional differences in public reactions to GM. Optimistically, these differences may connect to some acknowledgement, seen in our data, that the merits of gene drive might vary according to context, and (in a refreshing departure from standard deficit model framing) that publics are entitled to reach their own conclusions based on a variety of criteria. In principle, this turn to context *could* also be made compatible with arguments put forward to promote a 'slow race' (Leach and Scoones 2006) that would allow science and technology to work for marginalised communities in the global South, but this would require strong partnerships and an ability to consider gene drive in the context of different innovation pathways for grand challenges such as malarial vector control (Bartumeus et al. 2019).

Finally, our findings suggest that depending on how the sentiments expressed in our interviews play out in engagement on the ground, an application focus can enable meaningful, contextualised discussion of new technologies. Applications can allow engagement to go beyond abstract, high-level promises or reactions to a new technology, by exploring the implications of the technology in a particular socio-political context, and potentially also allowing a broader focus on multiple pathways (Doubleday 2007; Stirling, Hayes, and Delborne 2018). Evidence so far on gene drive suggests that at least some developers are approaching engagement differently from the top-down history of biofortification for malnutrition (Brooks et al. 2009). A focus on applications can show gene drive as having different sides – e.g. risks, benefits, but also uncertainties – and context-specificity, and potentially lead to more contextual, case-by-case discussions of the application of scientific insights.

Overall, these developments reflect the possibility that public engagement *might* have a meaningful impact on gene drive science, with research being responsive in some of the ways outlined in responsible innovation thinking (e.g. Delborne, Kokotovich, and Lunshof 2020). However, much will depend on how the field continues to evolve, and the extent to which voices for 'opening up' gene drive communication in inclusive ways (e.g. Cheung et al. 2020; Taitingfong 2020) coalesce and have impact. We have identified tendencies and possibilities based on promising lines of thinking amongst gene drive developers, but how such instincts to 'open up' are carried forward in practice in engagement processes and beyond remains an open question.

Conclusion

We aimed to explore whether gene drive stakeholders were open to – and were opening up – questions of "'which way?', 'who says?' and 'why?'" (Stirling, Hayes, and Delborne 2018) in communicating with wider publics. We have shown that there is some evidence of developers and communicators reflecting more openly on ways of making the

technology acceptable, and acknowledging there may be different ways to take gene drive forward depending on insights from engagement. These instincts are still mostly underpinned by a familiar instrumental interest in public trust and acceptance for deployment (e.g. Akbari et al. 2015; Min et al. 2017), but we do note some exceptions where developers are asking a more basic question: should gene drive be developed at all? In conclusion, we reflect on the implications of our research for how gene drive might unfold in the future, and for the responsibilities of different stakeholders as they continue to communicate with publics in search of better models of innovation for grand challenges.

Gene drive appears to be unfolding in ways that reflect the emergent, co-produced character of public engagement that scholars have identified in relation to other 'grand challenge' cases (e.g. Chilvers and Longhurst 2016; Chilvers, Pallett, and Hargreaves 2018). The focus on particular applications of gene drive (malaria, conservation) creates an opportunity for engagement to consider *purpose*; as in the case of engagement on geo-engineering, this can open up deliberation about the wider politics of the problem in question (Stilgoe, Watson, and Kuo 2013b), with a counter-tendency to narrow in on questions of safety. Which direction this goes in will depend on how tendencies to close down, open up or 'leave ajar' play out in future. But it is worth attending to the possibility that even instrumental efforts to close down or generate public acceptance can unravel in unexpected ways. In this respect, our language of 'leaving ajar' signals optimism but also caution and the need to attend to efforts to create and widen the openings emerging to date.

Even as public engagement on gene drive has been driven by a motivation to secure public consent for potentially contentious applications, it seems to be changing the way that scientists think not only about communication but also about their science. These scientists are forced to look at problems differently. So, while the pragmatic stance towards public communication remains an instrumental one in intent, it represents a loosening of closed positions, allowing exposure to diverse public reactions and alternative perspectives – leaving the door ajar for these to influence trajectories of the technology. As some interviewees acknowledged, this may turn out in ways that cannot necessarily be controlled. This has broader implications for responsible innovation – even if commitments to, say, responsiveness to publics initially seem tokenistic, the practice of engagement may still shift the dynamics of innovation to expose developers to new perspectives they had not previously considered or thought relevant, which may in turn influence their choices and decisions.

While these signs provide cause for optimism, the translation of public engagement into a primary focus on 'community' engagement potentially reflects a narrowing of engagement efforts, even when they proceed in the pragmatic or more open stances we have described. Our interviews suggest that many developers and communicators tend to equate the imperative of engagement with an issue of local consent for field trials, reflecting a similar theme in gene drive literature (e.g. Cheung et al. 2020; Meghani and Boete 2018; Najjar et al. 2017). Clearly, community engagement is crucial, for democratic reasons as well as because local engagement may reveal new knowledge and ways of comparing different innovation options (Hartley et al. 2019; Bartumeus et al. 2019). However, a focus on local consent alone may exclude the wider ethical and political questions around interventions (e.g. as Taitingfong 2020 argues in

relation to gene drive for pest control on islands; see also de Campos et al. 2017; Sandler 2020), and issues of ecological uncertainty and boundary-crossing (Leitschuh et al. 2018). Guidelines on identifying relevant parties may help keep the boundaries of engagement open (e.g. Kokotovich et al. 2020) but this still keeps the issues circumscribed to those assumed to already have a stake. By contrast, public deliberation approaches such as citizen assemblies assume that the net must be cast wider to bring in publics who may not otherwise be motivated to participate (Dryzek et al. 2020). What a broader public or, indeed, global public perspective might mean for gene drive needs further research.

In sum, pragmatic and open stances on gene drive are creating new opportunities for engagement with societal actors and issues, and requiring new ways of thinking about problems, which may democratise emerging technologies in unforeseen ways. They may also make transparent the interests and power differentials that tend to close things down. However, a key limitation of our study is that we focused on stakeholder accounts of how they approached public communication and engagement around gene drive, not processes of engagement which social scientists will surely need to investigate. As well, it should not be forgotten that the capacity to open up emerging technologies and be responsive in ways suggested in responsible innovation frameworks is shaped not only by stakeholder views but also by institutional settings and innovation configurations (Chilvers, Pallett, and Hargreaves 2018; Macnaghten and Chilvers 2014). In the case of gene drive, other social science work has shown that even stakeholders who accept the anomalous, eco-technological nature of gene drive tend to assume the technology is governable in ways that are open to question – but also, such attitudes are co-created and reinforced by existing institutions and their anomaly-handling strategies Evans and Palmer (2018). As social scientists proceed to collaborate with biophysical scientists on public engagement, they are well-placed to explore these structural constraints and affordances in future work. At the same time, we need to devote more attention to finding creative ways to open up (and out) conversations, to throw windows and doors wide open, as it were, to fresh perspectives, engagements and collective actions. Starting conversations with a focus on public good (Roberson, Leach, and Raman 2021), as opposed to the particular emerging technology, could be one way forward.

Human subjects ethical review

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