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New directions for participatory modelling in health: Redistributing expertise in relation to localised matters of concern

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ABSTRACT

Participatory modelling seeks to foster stakeholder engagement to better attune models to their decision-making and policy contexts. Such approaches are increasingly advocated for use in the field of health. We review the instrumental and epistemological claims made in support of participatory modelling approaches. These accentuate participatory models as offering a better evidence-base for health policy decisions. By drawing attention to recent modelling experiments in a sector outside of health, that of water management, we outline a different way of thinking about participation and modelling. Here, the participatory model is configured in relation to matters of 'knowledge controversy', with modelling constituted as an 'evidence-making intervention' in relation to the making of science and expertise. Rather than presenting participatory models as an improved technical solution to addressing given policy problems within an evidence-based intervention approach, models are alternatively potentiated as sites for the redistribution of expertise among actor networks as they seek to engage politically in a matter of concern. This leads us to consider possible new directions for participatory modelling in the field of health.

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Introduction

Participatory approaches to modelling are being trialled in a number of sectors (Dreyer & Renn, 2011; Voinov et al., 2016). They are increasingly advocated for use in the field of health research and policy (Darabi & Hosseinichimeh, 2020; Duboz & Binot, 2017). The rationale for adopting a participatory approach to modelling is typically instrumental, linked to claims that such models produce better knowledge and science, through enhanced stakeholder engagement, leading to better policy decisions (Voinov & Bousquet, 2010). Participatory modelling approaches can also connect with a normative sense that people ought to have a say in matters that affect them (Bots & van Daalen, 2008). They also reflect a broader push towards stakeholder and public engagement in knowledge-making. Linked to a crisis of public confidence in scientific expertise in recent years, this 'participatory turn' is seeing attempts to incorporate alternative forms of knowledge across multiple areas of governance (Chilvers & Kearnes, 2016; Leach et al., 2005; Tsouvalis & Waterton, 2012), including public health (Lancaster et al., 2017). Given increased interest in participatory

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modelling in the field of health, including most recently in response to pandemics such as COVID-19 (Adib et al., 2021; Aguas et al., 2020), we review the claimed potentials of participatory modelling approaches. Specifically, we draw attention to participatory modelling experiments in a sector other than health, that of water management (Landström et al., 2019; Landström, Whatmore, and Lane, 2011), to consider how participatory models in health might be opened up in new ways. We argue that participatory models can enable more experimental approaches to evidence-making which potentiate the redistribution of expertise in relation to localised matters of concern.

Participatory modelling

Participatory approaches hold potential across a variety of modelling traditions, including systems dynamics and agent-based modelling (Gilbert, 2008; Richardson, 2011; Vennix, 1996).[1] Though their participatory potential has yet to be fully realised (Atkinson et al., 2015; Badham et al., 2018; Darabi & Hosseinichimeh, 2020; Frerichs et al., 2020), there is a growing body of literature on participatory modelling in the health field, including in relation to: infectious disease (e.g. Gaydos et al., 2019; Goutard et al., 2015; Purse et al., 2020); cardiovascular disease (e.g. Kenealy et al., 2012; Loyo et al., 2013); respiratory conditions related to air pollution (e.g. Dianati et al., 2019); chronic conditions such as childhood obesity (e.g. Allender et al., 2015; Swierad et al., 2020) and alcohol-related harm (e.g. Atkinson et al., 2017); various aspects of healthcare provision from hospital systems (e.g. Furstenau et al., 2019; Ibrahim Shire et al., 2020) to community care for people living with HIV (e.g. Weeks et al., 2017); health economics, where patients had previously seldom been included in any form of direct decision-making (e.g. Squires, 2014; van Voorn et al., 2016); and community violence (e.g. Frerichs et al., 2016; Wang et al., 2020).

These participatory initiatives generally seek to enhance models for use in health policy in two ways: by generating 'better science' and by generating 'better decisions'. Including stakeholder expertise in the process of modelling seeks to improve the quality of models and their outputs, by better attuning them to their local contexts. In addition, collaborative modelling efforts may seek to use the model as a resource and tool of participatory engagement, including with stakeholders involved in decision-making and intervention development. Participation then, ranges from the *construction* of models to their *use* (Röckmann et al., 2012). In the former, attention centres on the model, with participation serving to build 'better models' through the 'triangulation of stakeholder expertise, data and simulation' (Zimmerman et al., 2016). In the latter, the model is decentred to serve as a device of participatory engagement, thereby facilitating collective decision-making and the 'better use' of models. Such participatory approaches to modelling may draw on the methods and techniques of participatory approaches more generally, such as those of participatory action research (Kesby et al., 2007; Voinov & Bousquet, 2010). To explore the claims made in support of participatory modelling approaches, we follow this common distinction between participation as a mode of bettering the 'science' and as a mode of bettering the 'use' of models, though we accept that this distinction is a loose one, with some initiatives doing both.

Critical perspectives

While participatory modelling efforts may tweak the way models are constructed and how they are put to use, they do not fundamentally challenge the taken-for-granted epistemological assumptions underpinning models and how they value evidence or expertise, and neither do they fundamentally challenge the taken-for-granted assumptions of the health problems which modelling interventions seek to address. This is the basis of the critique we offer here, which is informed by critical perspectives on participatory modelling. Accordingly, we draw attention to some recent experiments in participatory modelling from other sectors that seek to alter how modelling science might be done and the evidence and expertise that participatory models might produce (Barra et al., 2020; Landström, Whatmore, & Lane, 2011; Whatmore, 2009; Whitman et al., 2015). These are

experiments in participatory intervention which do not merely seek to enhance existing modelling approaches by inviting the input of stakeholders as part of this process, but which seek to *redistribute expertise* among the actors involved, thereby potentiating a different way of doing and using modelling. These more critical experiments challenge the epistemological foundations of dominant modelling approaches, into which participation is often added, to reconceive of participatory modelling as a political intervention in knowledge-making.

Such experiments in participatory modelling draw on ideas generated within the field of science and technology studies (STS) as well as in the sociological and anthropological study of science. The field of STS, for instance, positions models not as handles on an objective truth, but as material 'boundary objects' that mediate between different people and various practices (Knuuttila, 2005; Morrison & Morgan, 1999), functioning as 'epistemic tools' or 'artefacts' (Knuuttila, 2011), with the primary value of not representing the world, but 'teach[ing] us something about the thing it represents' (Morgan & Morrison, 1999, p. 11). Critical analyses of modelling in sociology and anthropology have focussed on the performativity of evidence-making to investigate how models are inscribed with, and in turn reproduce, social and material relations, with particular and contingent effects in the contexts in which they play a role (Callon & Muniesa, 2005; Mackenzie, 2006; Myers, 2015; Rhodes & Lancaster, 2019, 2020, 2021a, 2021b). These effects include the legitimisation of certain kinds of knowledge to the exclusion of others. Such exclusions can occur in participatory modelling and other forms of public participation in science and policy, despite commitments to pluralise knowledge (Lancaster et al., 2017). The critical experiments in participatory modelling that we review here build on the foundational work of STS scholars on the performativity and public engagement of science (Callon, 1999; Callon et al., 2009; Stengers, 2005) to invite consideration of how participatory models and experiments might operate as 'evidence-making interventions' (Rhodes & Lancaster, 2019). By bringing models and modellers together with multiple participants of diverse expertise, we explore the potential that participatory modelling can afford in efforts to remake scientific knowledge and redistribute expertise (Whatmore, 2009). We suggest that these promising new ways of doing participatory modelling might be trialled in the field of health.

Constructing models in participatory ways

The current widespread interest in participatory modelling, as is apparent in the literature we review below, has emerged in part from the acknowledgement, both within and outside modelling communities, of the limitations of traditional approaches to mathematical modelling in attuning to complex social situations (O'Donnell et al., 2017). Models, like all modes of science and evidence-making, 'reproduce and are constructed based on their different disciplinary boundaries', and are also 'limited by the data available and are influenced by perspective and even the political and funding arena in which particular research may be occurring' (Grant et al., 2016, p. 2). Attempts to overcome some of these limitations have oriented to better accounting for 'the social' in relation to model inputs and design, including by incorporating indicators which relate to human behaviour, social interaction and material context (Funk et al., 2010; Rhodes et al., 2020). The participation of stakeholders is positioned as a means of attuning models to their social contexts on the grounds that 'those who live and work in a system may be better informed about its processes and may have observed phenomena that would not be captured by scientists' (Voinov & Bousquet, 2010). By drawing from a diversity of perspectives and forms of knowledge models benefit from 'both the science of probability and more qualitative wisdom of experience' (O'Donnell et al., 2017). Participation then, seeks to better connect models with ideas of 'the social', attaching them to their local contexts, in an approach which affords modelling 'from below'.

The multidisciplinary modelling of Grant et al. (2016), which focuses on zoonotic disease in Africa, provides one such example of modelling 'from below'. They describe how research on Lassa fever conducted in local communities in Sierra Leone found that farmers burn their fields

following harvest, driving infected rodents towards villages, meaning that models must include varying, not stable, rates of rodent-human contact over the course of a year. The modelling of Ebola offers an additional example, wherein evidence generated from community consultation and anthropological research helped to better attune pandemic models of transmission and disease control to their situated contexts, especially as a counter-response to misguided assumptions in global infection control interventions regarding community engagement (Abramowitz, 2017; Abramowitz et al., 2015; Rhodes et al., 2020). In such ways, 'participatory data can help parameterize models with realistic data from the field' (Scoones et al., 2017), as well as guide modelling to represent and express the 'needs' and 'preferences' of local communities (Voinov et al., 2016). In such cases, however, the modelling process is not itself necessarily participatory.

Participatory modelling can also seek the direct involvement of stakeholders, such as policymakers, managers, or community members, in the development of models. This is typically envisaged in systems scientific terms as a process of 'developing a testable local theory of the system, proceeding from developing an initial qualitative understanding of the system, to rigorous mathematical evaluation of system behaviour' (Zimmerman et al., 2016). Here, for example, the modelling group 'collaboratively maps the risk factors and causal pathways relating to a chronic disease problem, and the mechanisms by which selected interventions have their effects' (O'Donnell et al. (2017). van Voorn et al. (2016) argue that stakeholders can be included in health economic modelling by contributing to the selection of model performance criteria and appropriate indicators for decision-making, thereby increasing model salience. In agent-based modelling of alcohol-related harm, Atkinson et al. (2018) maintain that stakeholders can offer 'meaningful critique of model structure, parameterisation and assumptions by stakeholders', which 'built greater confidence in the results produced by the model'.

Such initiatives are seen to serve several ends. They enable a fuller and more accurate picture than would otherwise be possible (O'Donnell et al., 2017). They are also expected to satisfy other aspects of model validation that go beyond scientific credibility (van Voorn et al., 2016), such as ensuring that modelling outputs are more appropriate to the problem that they are addressing (Purse et al., 2020; Zimmerman et al., 2016). Further, to the extent that the inclusion of local people and practitioners' perspectives can 'challenge model assumptions through local experiential and tacit knowledge' (Scoones et al., 2017), participatory modelling – even those approaches that involve less direct stakeholder participation, such as the examples outlined by (Grant et al., 2016) – would seem to hold a radical potential to disrupt the prevailing epistemological order in which certified scientific knowledge carries greater weight than alternative knowledges.

However, critical analyses suggest that in several respects these attempts in the domain of public health to make modelling processes participatory have not gone far enough. With the participation of non-conventional actors merely extending and supplementing existing modelling efforts, model assumptions and structures tend not to be opened up to scrutiny, re-affirming the privilege of science as well as of particular logics of explanation (Landström & Whatmore, 2014). The model is treated as offering access to, or better 'evidence-based' correspondence with, an objective truth or actuality, with the less empirically grounded knowledge that participants provide often treated as a problem of 'bias' as well as a threat to the assumed scientific neutrality of evidence-based models (Smith, 2020; van Voorn et al., 2016). The potential for stakeholders' expertise to alter the way that models are constructed and run, and thus, the way they build a logic of explanation and evidence-make a reality, tends to be limited (Ravera et al., 2011; Siebenhüner & Barth, 2005). The model, and the onto-epistemological assumptions underpinning it, continue to be taken as given – albeit with the acknowledgement that it can, through the participation of non-modellers, be done 'better'. In this (weak) version of participatory modelling, models become better attuned to participants' contexts, but the underlying logics, assumptions and privileges of how models do their evidence-making, including what constitutes expertise, is not challenged.

Using models in participatory initiatives

The emergence of participatory modelling also aligns with calls by for greater participation in decision-making by those affected, as well as greater public engagement in science in general, including to decentre scientific knowledge with alternative ways of knowing. Here, the question is less about the value that stakeholder participation can bring to modelling, than the value that models can lend to participatory decision-making and engagement. While modelling in health has long directly served policy-making (WHO, 2005, 2021), participatory modelling initiatives formalise the mediating function of modelling as an 'epistemic tool' of decision-making, and often extend beyond the inclusion of decision-makers in the private and government sectors to include diverse community stakeholders such as front-line workers and patients (Allender et al., 2015; Weeks et al., 2017). This becomes all the more relevant in a context in which 'non-conventional actors are entering the scene alongside the decision-makers traditionally responsible for public health' (Duboz & Binot, 2017). From this point of view, it is claimed that models take on:

> a somewhat different meaning, since they are less important as a product in themselves. Instead *the model becomes useful as long as it helps solve the particular problem that the stakeholder group is dealing with*. In some cases the model may have gleaming flaws in terms of the conventional model calibration-validation-verification process, yet will still be useful for stakeholders to reach a consensus and to make the decision (Voinov & Bousquet, 2010, p. 1274; emphasis added).

Here it is explicitly acknowledged that the model does not, and need not, achieve an 'objective' representation of reality, nor can or need it achieve accurate prediction of future outcomes. Instead its value consists primarily in its role as a boundary object around which to gather participants in a collective exercise. It is validated not against field data, but rather through 'the collective acknowledgement of its value through the learning and decision-making processes it fosters' (Duboz & Binot, 2017). The emphasis is on the value of the process of participation rather than that of the model itself. Instead, the 'usefulness' of participatory modelling in this approach is perceived to lie largely in its potential to enhance the capacity of participants to respond to the challenge with which they are concerned, with the goal to 'build capabilities as well as inform model structure' (Allender et al., 2015; Swierad et al., 2020). This involves going beyond merely gathering insights from participants to improve the model, as described above, to also using the model to develop a better understanding of the issue among participants. The model is seen as a 'tool' to help build a shared understanding or 'common "mental map" of the health problem' (Atkinson et al., 2015; Zimmerman et al., 2016).[2] It does this by functioning as 'an intermediary pedagogical device used to foster dialogue' (Binot et al., 2015; Duboz et al., 2018; Ibrahim Shire et al., 2020) and by facilitating 'translation […] between disciplines, e.g. clinicians, computer scientists and population health professionals' (Freebairn et al., 2017). The model can thereby serve as a 'rallying point' around which stakeholders can gather (Weeks et al., 2017). For example, health planners might use an interactive simulation model 'as a catalyst for convening diverse stakeholders in thinking about their strategic directions and policy priorities […] in an effort to align actions' (Loyo et al., 2013).

In these and similar participatory modelling projects, however, the 'problem' which the modelling is intended to address is taken as largely given; that is, available for 'better' conceptualisation, but not *re*conceptualisation. This reflects the critique by social scientists introduced above that models are seen to represent – to varying extents of accuracy and adequacy – a pre-existing problem, rather than understood as playing a part in constituting the problem they purport to address (Callon & Muniesa, 2005; Myers, 2015; Rhodes & Lancaster, 2021b). Although the emphasis on the 'accuracy' or 'objectivity' of the model shifts in favour of the processes of participation, we find that many of the onto-epistemological assumptions underpinning an 'evidence-based' approach remain unquestioned, including understandings of problems as exogenous to policy processes, and what constitutes 'useful' evidence-making 'tools' for decision-making. Indeed, enacting models as 'useful' tools makes and sustains a set of assumptions about knowledge, evidence, and rationales for policy

action, propping-up the idea of policy making as a rational process of authoritative choice (Lancaster, 2016)). What constitutes good participatory modelling is thus delimited by holding on to particular onto-epistemological assumptions dominant within evidence-based policy and science (Rhodes & Lancaster, 2021a).

However, a key element of the value of participatory modelling from this angle can be the collective or community learning that it enables (Freebairn et al., 2017; Minyard et al., 2014; Munar et al., 2015; Voinov et al., 2016). In this broader view of participatory modelling, which is apparent in the literature reviewed, all participants – modellers and non-modellers alike – stand to gain by learning from one another's input and interpretations (Ibrahim Shire et al., 2020). For example, in three participatory public health modelling projects in Australia, Freebairn et al. (2018) report that 'the content expert participants learned about dynamic simulation modelling and the modellers learned about the priority public health issue being modelled'. Decision-making is understood to then follow as the model facilitates collective reasoning through experimentation, enabling participants to 'play safely with alternative scenarios' (Royston et al., 1999) to assess multiple desirable and undesirable outcomes (Zimmerman et al., 2016).

This literature on participatory modelling in public health also tends to recognise the limits of expertise of all of the participants, for it 'creates a space in which no single actor holds all the knowledge or has the capacity to make decisions alone' (Duboz & Binot, 2017, p. 3). To an extent it also recognises the limits of the kinds of knowledge that have traditionally informed modelling and decision-making; for example, Kenealy et al. (2012) observe that their experiment in cardiovascular disease participatory modelling in New Zealand revealed that 'real value could best be achieved when the models were used within conversations and debates to which participants brought outside knowledge, values and commitment to making complex health service decisions'. However, here this approach can be seen to continue to cleave to the idea that knowledge exists independently of the modelling process, and can therefore be *carried in* by the participants in order to build a *fuller* picture. Again, in this version of participatory modelling, the model itself is seen as separated from the reality it observes and produces rather than as treated as an entangled and performative actor in the making of new knowledge (Callon & Muniesa, 2005; Myers, 2015).

In the process of dialogue, the diversity of participants and their perspectives is seen from this point of view as a resource, but also something to be managed. For example, participatory modelling is proposed by Goutard and colleagues in the surveillance of animal and zoonotic disease in developing countries in circumstances in which stakeholders have divergent points of view about the same situation, because it can include iterative, focused group discussions (2015). Others suggest that group model building offers a culturally sensitive way to include participants of diverse cultural backgrounds because it allows modellers to 'obtain narratives that deeply resonate with the community of interest' (Gerritsen et al., 2020; Swierad et al., 2020). Through better engaging stakeholders, participatory modelling is expected to reduce conflict, build trust and promote acceptance and ownership of the modelling outcomes (Voinov & Bousquet, 2010). These objectives are cast in more or less instrumental or normative terms in the literature. Less frequently it is noted that disagreement is not only something to be eliminated but might itself be productive. In their study of participatory HIV modelling, for example, Weeks et al. (2017, p. 596) describe how 'some scepticism within the group about the potential for this process and the resulting tool to be accurate, valid, and useful' in fact proved 'important […] by generating group responses to clarify and improve understanding and conceptual maps in the system'. But such a focus on achieving a 'shared understanding' of the problem and securing the acceptance of model outcomes can stifle or paper over difference of perspective among participants. Critical voices have long pointed out the potential for an emphasis on consensus in a variety of participatory initiatives to undermine their democratic ambitions (Kothari & Cooke, 2005; Mouffe, 2005; Rancière, 2001). In this context it is to deny that participatory modelling is an inherently *political* exercise, that is not only *noticing* of difference but *enacting* it through evidence-making and intervention (Rhodes & Lancaster, 2019).

The objective of building the capacity of stakeholders is associated with the promise that the modelling exercise will enable subsequent action to address the problem in question. Purse et al. (2020) argue that, for example, while 'predictive models for tropical zoonotic diseases […] are rarely scaled to intervention programs and ecosystem use', participatory modelling can address the 'disconnect between science, policy and implementation'. It is seen to do so because it 'provide[s] the basis for subsequent interventions to be owned and driven by that community' and can 'enhance the community readiness for change because the political will, leadership, and workforce are all on the same page and ready to go' (Allender et al., 2015). However, the focus here on how stakeholders may learn from the modelling tends to be at the expense of attention to how they might then go on to shape policy or practice following the initiative. In a review of the use of systems dynamic approaches in cross-sectoral community health initiatives, Cilenti et al. (2019) observe that most participatory modelling projects focus on improving understanding of the problem to which they are directed and only relatively few also involved action to respond to the problem. This suggests that in this approach participatory modelling can, in its emphasis on value of the process of participation, become detached from broader engagement with the conditions that prompted it. It also points to the possibility that while these participatory modelling initiatives celebrate the value of participants' engagement in collectively developing an understanding of a problem, actual decision and policy-making may remain dependent on the same standards of objective and neutral 'evidence-based' science that such participatory efforts purport to challenge. Assumptions about the linear relationship between problem identification, evidence translation, and subsequent response underpinning 'evidence-based intervention' remain intact, delimiting potential for a more open approach which might break down the imagined separation between evidence and intervention, knowledge and response, knowledge producers and users (Lancaster et al., 2020).

In these respects, participatory modelling, as described in the public health literature, tends towards incorporating participants into established 'evidence-based' decision-making structures and processes, rather than to remake these, thereby enabling participants to meaningfully affect the processes and outcomes of initiatives in new and unexpected ways. The emphasis on the 'usefulness' of the participatory modelling in the vein of the literature we have reviewed must then invite the question of for whom and to what ends participatory modelling is useful (and, moreover, what the emphasis on 'usefulness' assumes and unquestionably sustains). The participation of non-modellers and other non-conventional participants in these projects may leave intact the prevailing epistemological order in which the understanding of problems, and the policy interventions designed to address them, are grounded in certain types of knowledge and conceptual logics. This betrays a 'residual realism', whereby participants are taken to be pregiven and external to the object or issue of participation – a charge that has been levelled by some STS scholars against some forms of participatory practice (Chilvers & Kearnes, 2020). This in turn circumscribes the political scope of the exercise, reflecting the observation by STS scholars that 'invited public involvement nearly always imposes a frame which already implicitly imposes normative commitments – an implicit politics – as to what is salient and what is not salient, and thus what kinds of knowledge are salient and not salient' (Wynne, 2007, p. 107). In contrast, we propose that the difference that is invited through participation and dialogue is not something to be 'smoothed away' through negotiation towards a normative consensus, but a site of political deliberation and experimentation for what alternative evidence and realities models might be enabled to make through a different set of practices.

Experiments in participatory modelling

In recent years alternative models of participatory modelling have been trialled by geographers and STS scholars, including what have been referred to as 'competency groups' (Landström, Whatmore, Lane, Odoni, et al., 2011; Whatmore, 2009; Whatmore & Landström, 2011), a participatory action research approach (Whitman et al., 2015), and community modelling (Landström et al., 2019).

These modelling initiatives belong to a broader body of participatory experiments by STS scholars (e.g. Chilvers & Kearnes, 2016; Marres & Lezaun, 2011; Tsouvalis & Waterton, 2012). Taken together, these approaches seek to take seriously the politics of both the construction of the model and its use. This is 'another analytical framing' (Landström & Whatmore, 2014), which takes as its site of intervention not only participants but the model and its performance of evidence-making. Crucially, the aim here, as described of one such project on flood risk management, is not to 'bring local participants' knowledge into the formal decision-making process, but to bring science out of the institutional networks which have the authority to manage flood risk' (Landström & Whatmore, 2014, p. 597). Rather than seeking to incorporate non-traditional actors within the existing frameworks and modes of scientific knowledge-making, the aim is to reconceive science and redistribute scientific authority. Such initiatives are framed as *experiments* in the sense that they are open-ended attempts to make new knowledge and do things differently (Tsouvalis & Waterton, 2012). Whatmore and Landström (2011, p. 605) describe the competency group approach they deployed in two cases of flood risk modelling in Britain as a process of 'setting up an experimental apparatus to see what, if any, new political and scientific possibilities it might produce in a complex, 'live' situation.'

These initiatives see in participatory modelling a way to attempt to navigate through a situation of impasse or a problem. This approach views 'controversy as a dynamic source of change' (Landström & Whatmore, 2014, p. 584), following the work of STS scholars on the political potential that can be tapped in 'hot situations' (Callon, 1998), 'matters of concern' (Latour, 2004) and 'things that force thought' (Stengers, 2005). The competency group approach was 'developed for extreme situations in which normal flood management has failed and controversy ensued, situations in which new knowledge is needed to invent new options not conceivable with established means' (Landström & Whatmore, 2014). Such a situation had emerged at one of their sites, Ryedale, Yorkshire, when, in the context of a long-running public debate about flood management strategy, a major flood event in 2007 followed the government decision to withdraw funding for a proposed flood alleviation scheme. The participants were interested to be involved not only to inform flood knowledge but to 'make a difference' (2011) to the 'knowledge controversy' (2014) and political impasse that ensued. Such a situation of controversy, in which the political nature of the knowledge claims at play have already been laid bare, offers a foothold to fruitfully experiment with the competency group approach, but this approach should not be seen only as an alternative option when other measures have failed to overcome an impasse. Rather, it has the potential to offer a new way of engaging with and effecting change in a range of matters of concern.

Whatmore and Landström (2011) are, following Stengers (2005), interested in the potential for the situation of controversy 'to "force thought" in those affected by it and "slow down" the reasoning of established experts necessary to any redistribution of expertise.' In other words, they say, it can offer 'an apprenticeship to "what" is at stake in a knowledge controversy, and through which a new knowledge polity might assemble' (Stengers, 2005, p. 585). Addressing the critique above that invited participation – not to mention the model that it might centre on – tends to come already inscribed with an 'implicit politics' (Wynne, 2007), the process involves grappling with the nature of the problem and 'conceptualising together what a flood model need[s] to be able to do, which processes it should simulate and which questions it ought to address' (Landström, Whatmore, & Lane, 2011). This is a process of learning, in which new scientific knowledge is 'co-produced' 'through bringing scientists and publics together' (Landström, Whatmore, Lane, Odoni, et al., 2011, p. 1618; Tsouvalis & Waterton, 2012). This is, of course, a claim widely made in relation to a range of participatory modelling initiatives, both more and less critical. For the more critical approaches attempted by Whatmore and others, co-production refers not to the collaborative aggregation of knowledges, but rather captures how knowledge is *made through* practices as participants work together around a matter of concern.

For example, in the Ryedale competency group, the group broke with the traditional convention separating hydrology, which is concerned with rainfall, and hydraulics, which is concerned with

river flow, and developed a new modelling approach coupling the two 'in order for the model to answer the questions generated in the collective' about river flooding (Landström & Whatmore, 2014, p. 597). This new approach involved bringing together local knowledge of flooding in that specific place with scientific modelling skills, forming the foundations of a new mathematical model structure that, unlike existing models, was able to investigate the viability of the sort of landscape intervention, the upstream 'bund', that the group identified an interest in exploring. Co-production then, involves the constitution of social orders, which must be understood as 'situated achievements […] neither automatic nor guaranteed' (Whatmore & Landström, 2011, pp. 603–604). Whatmore and Landström (2011, p. 603) argue that it is necessary that 'any rethinking of the relationship between science and democracy attends as closely to the practices involved in constituting publics as to those of producing knowledge'. The participants of such initiatives are not publics in general, or even stakeholders in particular, that pre-exist in stable ways, but are brought together as 'concerned groups' (Callon, 1999), and as 'new collectives' (Latour, 2004), in relation to a matter of concern with which they have 'direct experience' (Landström, 2017). This means that participants are those 'whose primary and only stake […] is that they're interested in and participate in an experiment with scientists and social scientists of understanding their problem better' (Whatmore interview cited in Landström, 2017).

One of the ways that such connections are established and a new collective born is described by Landström, Whatmore, Lane, et al. (2011, p. 1618), following Callon et al. (2009), as a 'dynamic of "dissociations" and "attachments". This refers to how the project modellers have to go through an active process of 'dissociation in which they were establishing the goals of their research as distinct from existing practice', accompanied by a process of 'attachment', whereby scientists form 'new relationships that become constitutive of agency in relation to the matter of concern' (Landström, Whatmore, Lane, Odoni, et al., 2011). These processes are inherent to the progress of all scientific knowledge, but a participatory modelling exercise affords the opportunity to deliberately engage and widen the scope of such dissociation and association, enabling the assumptions and commitments of participants to be questioned, reaffirmed or made anew.

Citing Callon's observation that '"once a local collective exists and has begun its work of reconfiguration, it must have the means of constructing the circulation space of statements and other intermediaries that it produces"', Whatmore and Landström (2011, p. 595) recount how, for the Ryedale competency group, this construction of a 'circulation space' 'had to be addressed by the group as a practical matter.' The group did this by deciding to hold a public exhibition, which attracted considerable attention to their proposed flood management measure of the bund – after which 'the group's grip on how the bund model travelled, and who/what it assembled, loosened' (Whatmore & Landström, 2011). This understanding of the political engagement that is made possible by a competency group experiment reflects the ontological position that power to effect change does not exist in individuals and that participatory modelling therefore ought not to seek their empowerment (as proposed in mainstream participatory approaches; see above). Instead, Whatmore and Landström (2011) argue, citing Stengers, that the goal is not to empower the participants but to *empower the situation* by facilitating the emergence of 'publics capable of producing "*not as their aim but in the very process of their emergence*, the power to object and to intervene in matters which they discover concern them"' (cited on p. 606; emphasis added).

Conclusion

In this paper, we have discussed recent experiments in participatory modelling in the health and policy field that invite new directions, especially in the redistribution of expertise and how evidence might be valued. One layer of value is seen to lie in the access, via the range of perspectives and experiences that non-conventional participants bring to the process, to a wider range of data in order to generate a fuller picture of the model's object. Some initiatives also, or alternatively, place emphasis on the value of the participatory modelling process as an exercise in developing a

collective understanding of the matter of concern among the participants, in order to improve their decision-making capacity. Furthermore, we have drawn particular attention to the participatory experiments conducted by Whatmore and others which seek to go further, not only by sharing knowledge to produce collective learning among participants, but also by redistributing expertise among participants (Landström, Whatmore, Lane, Odoni, et al., 2011; Whatmore, 2009). In these approaches, participatory modelling potentiates change in the knowledge politics of the matter of concern. We suggest that such a critical and experimental approach to participatory modelling, along with the broader body of participatory experiments in STS to which it belongs (e.g. Chilvers & Kearnes, 2016; Marres & Lezaun, 2011; Tsouvalis & Waterton, 2012), has unrealised potential in the health field, especially given the prominence of models in health policy decision-making (Kucharski, 2020; Lakoff, 2017; Mansnerus, 2013; Rhodes et al., 2020).

It is noteworthy that the instances of critical and experimental participatory modelling that we have reviewed here relate to one sector, that of water and flood management. One explanation is that the field of water catchment management is uniquely 'antireductionist and epistemologically experimental', demonstrating a 'commitment to think fluidly, holistically, experimentally and through interesting new institutional arrangements' (Waterton & Tsouvalis, 2015). Another way of accounting for this is that the nature of the problems, the relevant knowledge, and the participants in this sector have tended to take specific forms that lend themselves to the experiments described above. Perhaps it is the case that the issue at hand – river flooding or subsidence, for example – is ongoing, relatively intractable, and accessible to observation by the people affected by it in such a way that it can result in the kind of knowledge controversy in which modelling based on local, experiential knowledge has the potential to cut through.

Such elements of the situation are of course not unique to the water sector. Situations of knowledge controversy, concerned participants, and powerful experiential knowledge all entangle as matters of public health concern. Perhaps in health, given its close relationship to evidence-based medicine, we have been reluctant to let go of the assumptions underlying evidence-based intervention, including assumptions about what counts as appropriate knowledge for policy and intervention, the linear relationship between evidence and intervention as knowledge is 'translated' into response, and problems as exogenous to evidence-making and policy processes (Lancaster & Rhodes, 2020; Rhodes & Lancaster, 2021a). We can imagine participatory modelling being taken forward as experiments in relation to various matters of public health controversy and concern, including in ways which extend beyond current participatory efforts to improve or attune models to their material situations. The current COVID-19 crisis offers one such example, drawing attention to the limits of mainstream evidence-based approaches and forcing thought on how to generate evidence in new, adaptive, responsive, multidisciplinary, and participative ways (Greenhalgh, 2020; Lancaster et al., 2020; Rhodes et al., 2020). There are, for instance, particular concerns surrounding the modelling of COVID-19 infection control in relation to school closures (Adams & Sample, 2020; Yan, 2021). While some modelling suggests that school closures have been effective strategy in previous influenza epidemics (Bin Nafisah et al., 2018), as well as in the current COVID-19 pandemic (Munday et al., [preprint]; Panovska-Griffiths et al., 2020; Prem et al., 2020; Zhang et al., 2020), the efficacy of school closures in the context of COVID-19 and previous coronavirus outbreaks have also been questioned (Ferguson et al., 2020; Viner et al., 2020; Yang et al., 2021). In light of calls to involve the people affected by school closures, not least the young people in schools themselves, in decision-making about such interventions (WHO Europe, 2021), participatory modelling might potentiate new ways of thinking about the effects of these interventions, as well as new ways of doing modelling and intervention. The COVID-19 pandemic sharply illuminates the entanglement of models and interventions with governance and public life; how knowledge and expertise come to bear in situations of need is not only an onto-epistemological concern but also highly political. Rather than merely attuning models to make them 'work better' in relation to pre-given interpretations of evidence and evidence-based intervention in the face of uncertainty, participatory modelling has the potential to yield new ways of tackling challenging knowledge controversies, as

well as situations of complexity in relation to health, by redistributing expertise among diverse voices not typically heard, and forging new ways of knowing and intervening.

Notes

1. Systems dynamic modelling is an approach to modelling stocks, flows, and the role of feedback in complex systems (Richardson, 2011). Agent-based modelling explores the behaviour of agents who act according to certain rules derived from the state of the agent, the state of the environment, and the agent's spatial location (Voinov & Bousquet, 2010).
2. Most of the participatory modelling projects reviewed consist, in part or in their entirety, in a conceptual mapping exercise. Some also contain computer-based simulation modelling which builds on the mapping exercise.

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