genetics, industry, government, social science, bioethics or moral philosophy. The risks include an 'echo chamber effect', where one communicates primarily with those who are members of the same disciplinary culture, or think through the same disciplinary lens. This interferes with transdisciplinary synthesis of scientific evidence and can perpetuate or augment the existing knowledge silos in genome medicine [13,15].

Innovation actors operating with vastly different motivations and aspirations, when left unchecked, cannot produce knowledge synchronously at a scale that meets the demands of large-scale post-genomics applications. While one may reasonably argue that synchronous knowledge production in science is not always important (in undirected 'blue sky research', for instance), applied research such as public health pharmacogenomics requires complex collaboration and coordination to generate innovative health products that can be used for population health. One witnesses this in the current global pharmacogenomics research that is materializing in diverse 'scientific cultures' [3,13,16,17]. Consistent with this, a scoping study associated with the UK James Lind Alliance report (Tackling Treatment Uncertainties Together) on the broader importance of coordinated R&D in health sciences has underscored the need for co-ordination between upstream (research agenda setting) and downstream (implementation and uptake) research: The evidence for informing decisions about health treatments is based largely on research agendas set in an uncoordinated fashion by academics and industry. The launch of the National Health Services (NHS) Research and Development programme, in 1991, instigated a needs-led programme of commissioned research to counterbalance the responsive programmes which rely primarily on researchers suggesting potential research projects to funders. [5]

In addition to professional blind spots in science, previous discussions of genomics have exposed otherwise unchecked and embedded self-interests, whether from academia, government, industry, media or patient advocacy groups, not to mention bioethicists, social scientists and philosophers reflecting on genomics, innovation and society. Scientists and technology-driven expert commu-

is neither driven nor influenced by technology alone. In the current post-genomics era, there have been seismic shifts in the way scientific knowledge is produced. Evidenced by various open science initiatives connected by digital media and Web 2.0, post-genomics knowledge is co-produced in a highly distributed manner. It is extending well beyond the cloistered halls of academia and the laboratory bench space to hitherto unprecedented locales. It impacts, and is being impacted by, new stakeholders such as citizen scientists, developing countries and patient advocacy groups [3,16,17]. These stakeholders are contributing, in some cases, to complex scientific tasks [27].

We offer a new perspective that focuses on how scientific knowledge is co-produced in order to understand the emergent forms of collaboration in 'post-genomics pharmacogenomics'. Such a perspective moves us away from codified static knowledge where making information available, transmissible and reproducible across scientific sites was traditionally at the core of the science enterprise. Here, we emphasize the 'knowing' aspect of knowledge production: how is knowledge produced, validated, negotiated, made sense of and enacted in local settings? How is knowledge translated across locations? How does knowledge travel or get translated across organizational boundaries and epistemologies (that is, ways of knowing: how do we know what we know)?

Taking such a dynamic and variegated view of knowledge generation is increasingly important in an age where social media-type technologies enable the emergence of global online communities, support knowledge reuse and remixing, and afford the emergence of generative and massively open forms of collaboration.

Citizen science and crowd-sourcing have recently demonstrated the contributions that can be made by non-professionals (for example, online computer game players) in solving complex scientific problems such as protein structure prediction [28]. Citizen science leverages natural human abilities such as visual pattern recognition or spatial problem-solving skills aided by online computer games. In geographically distributed forms of global science projects such as the Encyclopedia of Life, which documents all living species known to science, non-experts also contribute to data collection in the form of video, sound, images, graphics and text. A recent report on open science released by the UK Royal Society further illustrates the promise of 'massively parallel collaboration' for upstream scientific discovery, study design and research question formulation: Live and open debate played out via wikis and blogs have changed the dynamic of academic discussion - sometimes in extreme ways. In January 2009 Tim Gowers, an eminent mathematician and recipient of the Fields Medal, launched the Polymath Project, a blog serving as an open forum for contributors to work on a complex unsolved mathematical problem. He posed the question: "Is massively collaborative mathematics possible?" He then set out the problem, his ideas about it and an invitation for others to contribute to its solution. 27 people made more than 800 comments, rapidly developing or discarding emerging ideas. In just over a month, the problem was solved. Together they not only solved the core problem, but a harder generalisation of it. In describing this, Gowers said, "It felt like the difference between driving a car and pushing it." [29]

This resonates well with Michael Gibbons and colleagues' concept and project of 'Mode 2' knowledge production [24-27]. Mode 2 knowledge is a simultaneous 'co-production' by a multitude of heterogeneous actors, both experts and non-experts/non-professionals, dispersed in diverse geographical and disciplinary locales and scales. Mode 2, as explained by Barbara Prainsack, is 'where knowledge production takes place inside and outside of organisations and institutions that have ceased to fit within any clear categories' [30].

The concept firmly recognizes the 'social construction' of scientific knowledge and that the boundaries between science, technology and society are highly porous. That is, scientific knowledge is a co-product of technology and natural laws, as well as human values and epistemologies embedded in scientific inquiry. This contrasts sharply with the scientific practices of the original founders of pharmacogenetics in the 1950s, where knowledge was

production systems that it is attempting to analyse - wide social distribution, transdisciplinarity, the need for social robustness, and the creative potential of controversies. [26]

Mode 2 knowledge and the biological citizen

normative conclusions (for example, an ethical/unethical technology, person, industry), as with natural scientists, can also be subject to influences by their own value systems and personal career agendas [19,21-23].

One of the unique aspects of the Human Genome Project, in contrast to traditional discipline-bound sciences such as pharmacology, was the intentional funding of research into the attendant ethical, legal and social issues (ELSIs) - a research mandate that continues to the present day in that all research proposals submitted to the US National Human Genome Research Institute must include activities in the ELSI space.

While there is no doubt that these e□orts remain crucial, and have moved genomics R&D increasingly to the Mode 2 knowledge space (relative to pharmacology, for example), there is growing debate within the ELSI community where the next direction(s) should be [12,39-42]. It is noteworthy that pharmacogenomics is a 'hybrid' field that draws from both genomics and pharmacology. While genomics now resides within the Mode 2 space, pharmacology as a discipline has lagged behind. For example, pharmacology research does not routinely carry out ELSI research as a contrast to genomics R&D. Indeed, if we reflect on the panoply of contemporary biomedical disciplines in existence, social pharmacology is 'missing' or kept silent, and sadly does not exist as a formal university department, despite the legitimate recognition of social medicine or social psychiatry in 21st century universities. □is is an important gap that is impacting pharmacogenomics as a hybrid science that rests in part on pharmacology scholarship.

As a way forward, a critical examination of how bioethics questions are framed, and the previously unchallenged role of bioethics as an innovation regulator, will be important considerations in planning for translation of pharmacogenomics innovations to public health practice. To this end, it is interesting to note that the myth of bioethics and social science as being inclusive and primarily intended to serve the best interests of

caution is necessary: applying ‘democracy’ to post-genomics R&D may raise false expectations about binding political norms. The concept of public or citizen ‘participation’ (or better, ‘collaboration’), on the other hand, achieves a more suitable framework for positioning public engagement in post-genomics governance and innovations.

The idea of multiple levels of citizen participation in decision-making can be traced back, at least in modern (and Western) times, to Sherry Arnstein’s influential 1969 article on the eight levels of citizen participation, ranging categorically from ‘nonparticipation’ to ‘tokenism’ to ‘citizen power’ [46]. More recently, publicly funded research agencies are engaging in open science as noted above [28], and in the spirit of transparency, state and

action, one model that may overcome some of these pitfalls and o□er a better avenue for translating pharmacogenomics to public health action is 'wiki-governance', which horizontalizes the traditional decision-making hierarchy and situates itself within a more globally networked and mutuality-

paramount and much knowledge remains unknown or indeterminate, models such as wiki-governance can e□ectively bridge science and democracy to achieve multiple pathways for citizens to rightfully envision themselves as co-creators of genomic science, policy, and successful and sustainable innovation.

Concluding remarks

Every first order action has second order consequences. With the rise of Mode 2, long-held assumptions of scientists and science are being challenged in the post-genomics era - what it means to be a pharmacogenomics

York: Macmillan; 1914.
5. Oliver S, Gray J: *A B b a Re ea c Re t ab t Pa e t ', C ca ' a d Re ea c e 'P t e Ne Re ea c* . London: James Lind Alliance; 2006.
6. Chalmers I, Glasziou P: Avoidable waste in the production and reporting of research evidence. *La ce* 2009,

60. Shanker A: Genome research in the cloud. *OMICS* 2012, 16:422-428.
61. V