Enhancing Socio-technical Governance: Targeting Inequality in Innovation through Inclusivity Mainstreaming

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ABSTRACT

Socio-technical governance has been of long-standing interest to science and technology studies and science policy studies. Recent calls for midstream modulation direct attention to a more complicated model of innovation, and a new place for social scientists to intervene in research, design and development. This paper develops and expands this earlier work to demonstrate how a suite of concepts from science and technology studies and innovation studies can be used as a heuristic tool to conduct real-time evaluation and reflection during the process of innovation – upstream, midstream, and downstream. The result of this new protocol is inclusivity mainstreaming: determining if and how marginalized peoples and perspectives are being maximally incorporated into the model of innovation, while highlighting common problems of inequality that need to be addressed.

Keywords

poverty, inequality, innovation, inclusivity mainstreaming, policy, evaluation and reflection

ACKNOWLEDGEMENTS

Logan Williams thanks NSF DDIG 1153308 and the CAORC Multi-country Fellowship, for the funding that allowed her to collect the data about Aurolab. Both authors thank David J. Hess, and two anonymous referees for their comments on an early draft.

INTRODUCTION

Socio-technical governance today produces inequality: extreme wealth inequality between CEOs versus consumers (Peetz 2015); design inequality between white men and other social identities using information and communications devices (Oudshoorn, Rommes and Stienstra 2004; Pierce 2009; Roth 2013); health inequality between white men and other social identities with medical care needs (Read and Gorman 2010; Hoffman et al. 2016). Unfortunately, inequality in science and technology further disadvantages marginalized people. For example, algorithms increase inequality in US social services for people previously marginalized by low-income (Eubanks 2018). In another example, women (already marginalized by gender) who take accelerated hormone schedules as part of voluntarily donating their eggs for controversial STEM cell research may have serious health problems, which they cannot afford to treat (Benjamin 2013). These examples point to the question: How can we enhance socio-technical governance to better serve the marginalized?

In recent years, socio-technical governance has been of increasing interest to science and technology studies and science policy studies. This interest is demonstrated by scholarship on constructive technology assessment (Schot and Rip 1997), real-time technology assessment (Guston and Sarewitz 2002), socio-technical integration research (Fisher 2007), and responsible research and innovation (Macnaghten et al. 2014; Stilgoe, Owen, and Macnaghten 2013). The above four models conceptualizing socio-technical governance differ from the status quo practice of science and technology policy because they reject the linear model of innovation (Rafols et al. 2011, 633-634); instead they focus on reflexivity, and public engagement (Fisher, Mahajan and Mitcham 2006; Smith and Stirling 2007).

Additionally, three other theoretical frameworks, frugal innovation (Papaioannou 2014), grassroots innovation (Smith et al. 2016), and below the radar innovation (Kaplinsky et al. 2009), share specific concerns around: how the uneven balance of power and resources affects the production and inauguration of knowledge and innovation, the involvement of marginalized communities, and development progress at multiple scales but particularly in local communities.

Altogether, this plethora of existing theoretical frameworks for socio-technical governance highlights a need for scholarly guidance that provides more equitable and just science and technology solutions for marginalized communities.

This paper will enhance scholarship on socio-technical governance of science and technology to impact marginalized communities. We begin by uncovering a knowledge gap in theories of socio-technical governance. Then we continue by reviewing literature on undone science, undone technology, inclusive innovation, and their varying approaches to targeting inequality in science and technology policy to address the issues of marginalized communities. Next, we summarize our new intervention, the "targeting inequality protocol". Afterward, we describe our methodology. Then, we introduce two cases, utilizing secondary sources, which we evaluate using the "targeting inequality protocol". Finally, the paper ends with a discussion of the protocol's applications, limitations, and directions for future work.

SOCIO-TECHNICAL GOVERNANCE: UPSTREAM, MIDSTREAM AND DOWNSTREAM

In order to target inequality in science and technology, a simple metaphor suggests there are two main points to intervene into the socio-technical governance process: upstream and downstream. Both upstream and downstream governance processes typically are facilitated by institutions such as government agencies, think tanks, committees of elected officials, industry associations, and consumer associations. Upstream policy-making processes affect science and technology research agenda-setting, including the authorization (or suppression) of specific research trajectories. Governments use laws, regulations, and standards to shape scientific and technological trajectories (Fisher, Mahajan and Mitcham 2006). In the US, the federal government shapes upstream science by maintaining a productive innovation environment; it sets budgets for agencies that fund science, sets research goals, and regulates scientific inputs and processes (Neal, Smith and McCormick 2008). Also, policy-makers utilize scientific knowledge to craft policy, provide government oversight and strengthen their policy positions (Neal, Smith and McCormick 2008). One example is President Obama's 2013 BRAIN (Brain Research through Advancing Innovative Neurotechnologies) initiative which directed federal agencies to fund neuroscience research and technology development. The surge of federal funds available due to this initiative helped shape many US scientists' research questions around this new scientific bandwagon (Budtz Pedersen and Hendricks 2014; Fujimura 1988).

Downstream policy-making processes affect users after a science or technology has been developed, diffused and adopted. In downstream processes, governments use laws, regulations and standards to intervene in markets shape the use of science and technology (Fisher, Mahajan and Mitcham 2006). Downstream processes more directly affect individual or group access to already existing scientific knowledge or technology production (Fisher, Mahajan, and Mitcham 2006). For example, the US government banned 3D printer gun blueprint distribution. The scientific and technical knowledge exists, but the government protects the public by preventing this information's release.

Upstream and downstream processes do not fully epitomize the innovation process; therefore, scholars have added midstream modulation (Fisher, Mahajan and Mitcham 2006). Midstream modulation characterizes the actions of the scientists and engineers to shape the innovation system. It emphasizes that science does not follow a linear path from basic research to applied research. While the metaphor of a direct movement of science and technology through upstream research ideation followed by downstream diffusion in the market is useful, it does not match the actual socio-technical governance process. In reality R&D has a variety of eddies, turbulence and currents that loop back, intersect, and feed upon themselves to impact the innovation system (Fisher, Mahajan and Mitcham 2006; see Figure 1). Inventors might first develop a product and then go back to understand the science or they may develop the science and technological application at the same time (Stokes 1997).

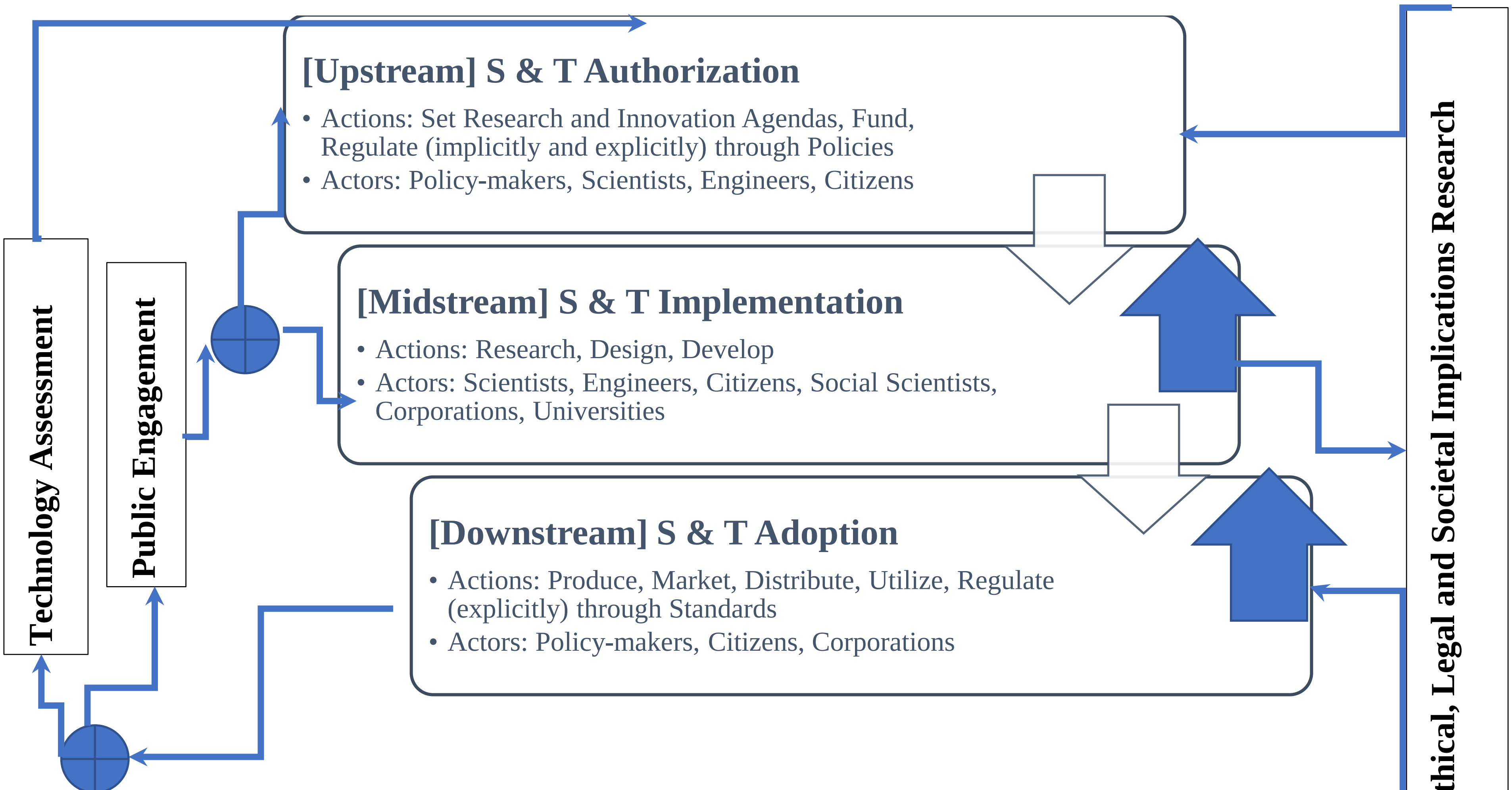

Figure 1 Science and Technology Governance Stages

These stages are non-linear, where a linear science and technology policy process (authorization, implementation and adoption) is complicated by nested and iterative interactions by various actors, with different levels of engagement, across and between the three overlapping and fluid stages upstream, midstream and downstream (see Fisher, Mahajan and Mitcham 2006)

Midstream policy-making processes affect scientists, engineers, and policy-makers during the research, design, and development stages. In science and engineering laboratories, midstream modulation points towards the potential for social scientists to work together with engineers and natural scientists to intervene in research design and development for social impact (Fisher, Mahajan, and Mitcham 2006; Fisher and Schuurbiers 2013; Gorman et al. 2013; Schuurbiers 2011).

The streams metaphor of socio-technical governance with three overlapping and interrelated phases of upstream, midstream, and downstream directs attention to a more complicated model of innovation. In the next two sections, we argue that recent STS and innovation studies concepts about science, ignorance and inequality can further enhance socio-technical governance.

UNCOVERING PROBLEMS IN SOCIO-TECHNICAL GOVERNANCE

In sociology of ignorance, undone science is systematically-produced negative non-knowledge that would, if available as knowledge, be of interest to marginalized groups and social movements (Hess 2015). Negative non-knowledge refers to the known unknowns that a research system, controlled by powerful elites, deliberately chooses not to pursue because of practical and political interests (Warren 2015). Previously, Author 2 and Author 1 (Under Review) suggested there are three problems with socio-technical governance causing negative non-knowledge and one problem with socio-technical governance that causes restricted access to normal science. We briefly summarize those problems again here as the first four of six problems that generate inequality in science and technology innovation upstream, midstream and downstream: (1) infrastructure problem (scientific bandwagon upstream creates non-knowledge), (2) powerful interests problem (chilling effect midstream and downstream creates non-knowledge), (3) Eurocentric worldview problem (ethnocentric effect upstream and midstream creates non-knowledge), (4) price-gouging problem (high prices blocks access to normal science downstream), (5) profit incentive problem (narrow focus on blockbuster invention creates non-market and non-artifacts upstream), and (6) privileged user problem (user identity bias creates non-users and non-artifacts midstream).

The first issue is the **infrastructure problem** which occurs upstream in socio-technical governance. This problem relates to which research questions are funded, ignored, or de-funded and may cause a scientific bandwagon – a popular research or design problem that attracts public attention, funds, junior researchers and innovators (Author 2 and Author 1 Under Review citing Budtz Pedersen and Hendricks 2014, Fujimura 1988, and Whitley, Gläser, and Laudel 2018). Rarely discussed is that choices about what research problems to pursue (or ignore) typically maintains the status quo of social relations, to the disadvantage of marginalized groups. Therefore, in the infrastructure problem, undone science occurs upstream and involves "a structured absence that emerges from relations of inequality that are reflected in the priorities for what kinds of research should be funded" (Hess 2016, 33).

Another problem that occurs upstream and midstream in socio-technical governance is that **powerful interests** create a chilling effect: they prevent the creation and dissemination of research studies that could negatively reflect upon them. Powerful interests can oppress scientists in their workplaces and suppress research questions (upstream) or research findings (midstream) (Author 2 and Author 1 Under Review citing Greenberg 2003; Delborne 2008; Martin 1981). As a consequence, the powerful interests create undone science as an artificial absence of scientific research pertaining to socio-technical problems in society that would impact marginalized groups. One common example is the power the tobacco industry had to suppress research on how smoking and chewing tobacco causes cancer.

A third problem that occurs in upstream and midstream socio-technical governance is a **Eurocentric worldview** can implicitly and overtly bias the research and development process. In science, a Eurocentric worldview assigns greater value and merit to science that uses Western methods and epistemology to solve problems interesting to Westerners. This results in higher education gatekeepers (e.g., administrators and grant program officers working upstream, principal investigators and dissertation committee chairs working midstream, etc.) emphasizing Western science above any other knowledges or knowledge systems (Author 2 and Author 1 Under Review citing Englander 2014; Dotson 2014; Hess 1995; Harding 2008; Pereira 2018). Such an emphasis on Western science creates undone science as preventing "new ways of thinking about old scientific problems…. new problems and… new methods or topics of inquiry"(Hess 1995, 185). Scholars and practitioners who are focused on non-Western knowledges or knowledge systems experience this Eurocentric worldview as "epistemic exclusion"(Cech, et al. 2017; Pereira 2018; Settles, Buchanan and Dotson 2018).

A fourth problem with downstream socio-technical governance is the **price-gouging of publicly funded research**. Ignorance can be created when access is restricted to normal science when the high fees charged by corporations, through licenses or patents, block marginalized groups from using the scientific knowledge (Author 2 and Author 1 Under Review citing Parthasarathy 2017; Contreras 2013). Since scientific knowledge is often created incrementally, building layer-by-layer upon previous knowledge, this restriction has the potential to create future non-knowledge.

In addition to the above four problems that create current and future non-knowledge, there are two problems related to undone technology (Author 1 2017) that create non-users, non-producers and non-artifacts.

A related problem operating upstream in socio-technical governance is a narrow incentive – **the profit incentive** – for technology research, design, and development. Wealth inequality has increased globally and this is connected to the shareholders' strong influence in corporate governance (Clarke, Jarvis, and Gohalamshahi 2018). Large R&D firms focus on creating blockbuster inventions they can patent and sell in order to make money for shareholders (Author 1 2017; Clarke, Jarvis, and Gohalamshahi 2018; Lehoux et al. 2014). These companies give little attention to developing products for marginalized groups (Author 1 2017 citing Eglash 2004, Eglash 2016 and Godin 2015). Such singular focus on producing technology for profit restricts who becomes a technology producer. In addition to creating non-producers, this misaligned incentive creates a non-market of immaterial non-artifacts. Corporations are uninterested in the smaller margins at high volume made by producing low-cost products for the bottom billion. Corporate disinterest makes poor people around the world into a non-market for goods available at an unaffordable price (Author 1 2017 citing Prahalad and Hart 2002). This lack of interest manifests upstream in socio-technical governance during invention and marketing.

The sixth problem is that implicit user identity bias midstream during research, design and development tends to create **privileged users** along with non-users and non-artifacts. The designers, who are typically high-income, white men of European descent, are using the I-methodology (Oudshoorn, Rommes and Stienstra 2004): they are designing for their own needs and they are not actively considering others' needs. Implicit user identity bias occurs when any design team (even one diverse in composition) utilizes blind inclusion where there is naïve (or no) attention to gender, age, class, race, or other components of user identity in design (Oudshoorn, Rommes and Stienstra 2004; Pierce 2009). For example, early photography equipment and computer video camera designs demonstrate inattention to lighting for dark skin tones (Roth 2013). Meanwhile, the design of information and communication technologies, ostensibly developed for senior citizens, demonstrates inattention to class and age (Pierce 2009). The privileged user problem creates technology non-users (Winner 1980; Wyatt 2003) and non-artifacts. This privileged user problem tends to occur at the stage of research, design, and development – midstream in the process of science and technology governance.

The six problems described above primarily highlight inequality upstream and midstream in socio-technical governance. Meanwhile, the ladder of inclusive innovation (described below) is a useful heuristic tool to evaluate innovations that have already been developed and are in the stage of being mass-produced, disseminated and used downstream.

EVALUATING OUTCOMES IN SOCIO-TECHNICAL GOVERNANCE

The ladder of inclusive innovation was developed by scholars as a framework to guide and assess innovations. It has six rungs; higher rungs are progressively harder to reach since more is required for an innovation to be inclusive (Heeks et al. 2013).

The first rung on the ladder of inclusive innovation is intent to include, where, the innovators must propose how their innovations will be inclusive. At this lowest rung, their innovations do not have to prove effective or useful. These innovators have a shift in mindset from prior innovators, now they are at least thinking to develop something to help marginalized communities (Heeks et al. 2013).

The next level, inclusion of consumption, categorizes an inclusive innovation if it is used by a marginalized community. The innovation should be: priced correctly, accessible, and useful. An innovation could be categorized at this level if it was initially consumed. However, the innovation does not have to make a long-term positive impact on a marginalized community. It may have a negative or negligible impact. The authors have seen many projects that fit onto this rung (i.e., ranging from wells to solar panels) spread across sub-Saharan African and South Asia.

The third rung of the inclusive innovation ladder is inclusion of impact. At this rung the innovation has demonstrably positive impacts on marginalized groups. The positive benefits could be greater income, easier livelihoods and more social welfare. Most innovators want their inventions to at least achieve this rung.

For level 4 of the ladder, an innovation is inclusive if the marginalized group is involved in the innovation process (Heeks et al. 2013, 5). Heeks et al. (2013) break down level 4 into two sets of sub-steps (see Figure 2). The first set of sub-steps, called the sub-processes of innovation (Heeks et al. 2013), are similar to the stages of a technology's lifecycle, or the value chain of invention (Author 1 2017). Level 4 of Heeks et al.'s (2013) ladder of inclusive innovation matches the stages of research, design, and development in a technology's life cycle. This paper directly addresses the second set of sub-steps, which come directly from Sherry Arnstein's (1969) earlier work on citizen's power and the ladder of public participation.

Level 5, inclusion of structure, focuses on evaluating the institutions that encourage inclusive innovation. At this rung an innovation cannot simply be developed in a company in a wealthy country by residents from a marginalized community. Rather, marginalized groups must participate in governing the institutions that control patenting, markets, education, distribution, employment, etc. and so forth.

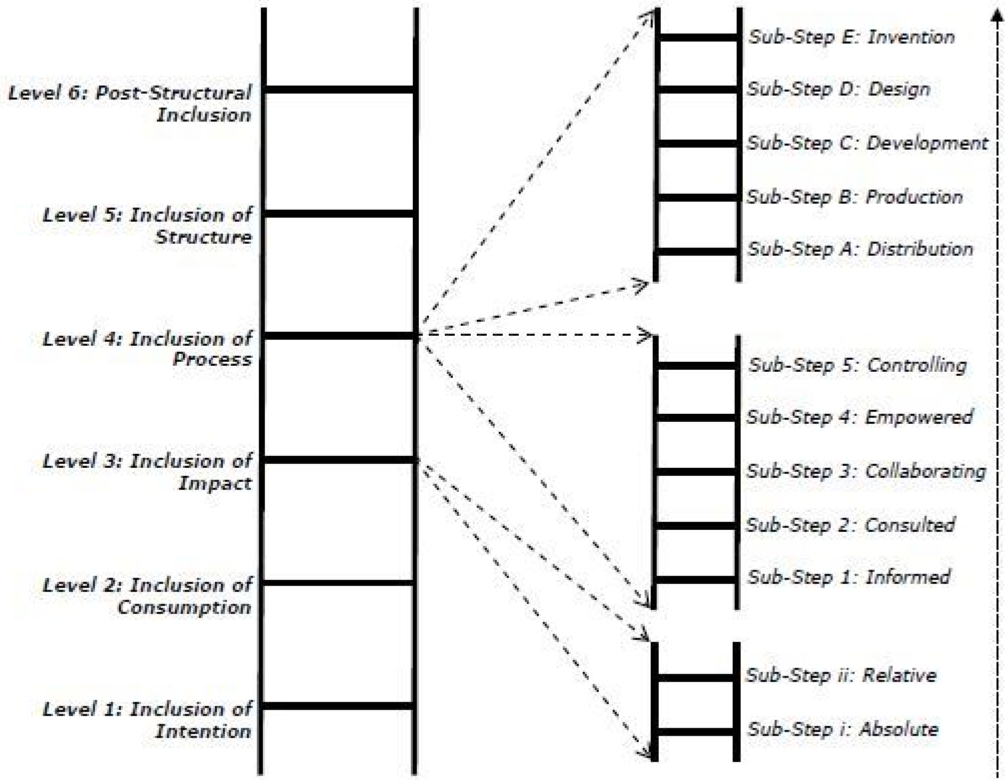

Figure 2 Heeks et al. (2013) Ladder of Inclusive Innovation with Sub-steps for Levels 3 & 4

The final level, post structural inclusion is the most challenging level to achieve and the most amorphous to define. At this level, the theoretical frameworks, language and understanding of inequality need to change to make socio-technical governance more inclusive. It would be difficult for a single innovation to achieve this rung, but overtime a series of innovations can reshape how society approaches inclusive innovation. An example of post-structural technologies are household appliances and their ability to transform (or maintain) the roles that women, men, children, and servants play in industry and the household (Cockburn and Ormrod 1993; Cowan 1985).

The ladder of inclusive innovation does not offer practical guidelines for post-structural inclusion. However, starting with Arnstein's work in the 1960s, there is a substantial literature on public participation in science that could inform future efforts. For example, scholars, technology developers, or policy-makers interested in using the inclusive innovation ladder can rely on experiential data about the benefits of structured public participation from consensus conferences at Arizona State University and in the Netherlands (Guston 1999; Tomblin et al. 2017). Future scholars, technology developers, and policy-makers can build upon this prior work to be selective about the methods of engaging non-experts into discussion in order to move towards post-structural inclusion.

The inclusive innovation literature can benefit from acknowledging that powerful interests drive undone science; this creates negative non-knowledge that impacts development. In development, many times poverty stems from both the entrenched political, economic and social issues that exclude certain groups and the inequality that arises from allocating limited resources. For undone science, these disparities create negative non-knowledge. Negative non-knowledge in development prevents inclusive innovation. The challenge is untangling negative non-knowledge from a resource deficit. Politicians may not pursue a certain project to help a poor community because it conflicts with their interests. Alternatively, politicians may find they are unable to pursue a project because they cannot afford to pay for necessary infrastructure. Sorting out these differing motivations, powerful interests versus low economic resources, is difficult.

Undone science, undone technology, and inclusive innovation should consider how to distinguish and understand by what means inaction blocks knowledge flow or stops innovation production. Prior work on undone science tends to focus on intentional acts by corporate or government parties with interest in particular scientific outcomes. However, sometimes negligence through inaction (whether intended or unintended) can be just as damaging as active stoppages or blockages. Privileging inaction as an analytical lens means the analysis is more focused on what has not been done, and who is not being served, i.e., non-users.

In the next section, we use the socio-technical governance streams metaphor to explore the utility of linking together undone science and undone technology (see Hess 2016; Woodhouse 2010; Williams 2017) with inclusive innovation (see Heeks et al. 2013; Heeks, Foster, & Nugroho 2014) to create a new protocol. This new protocol is intended for mainstreaming discussions of addressing inequality into socio-technical governance by, firstly, highlighting common problems of inequality that need to be addressed and, secondly, determining if and how marginalized peoples and perspectives are being maximally incorporated into processes.

NEW INTERVENTION: THE TARGETING INEQUALITY PROTOCOL

Although many public administrators and public officials are interested in creating innovation that addresses inequality, there are not many tools available for mainstreaming discussions of inequality into innovation processes, standards, and policies. Frameworks such as responsible research and innovation (Stilgoe, Owen, and Macnaghten 2013), and, responsible innovation in health (Lehoux et al. In Press; Pacifico Silva et al. 2018) gesture towards inclusivity mainstreaming. These prior frameworks are broadly focused; therefore, their potential to address the patterns of inequality inhibiting innovations for marginalized people has yet to be realized. Below, we will describe a new protocol that focuses more narrowly on enhancing the outcomes for marginalized peoples for innovation processes, standards, and policies.

In summary, undone science, undone technology and inclusive innovation provide useful insights to target inequality in socio-technical governance that impacts marginalized groups. Undone science is a durable concept because it elucidates disparities and hidden trends that create negative non-knowledge. Due to unequal power dynamics, as long as scientists explore some phenomena, they will always neglect others. Additionally, inclusive innovation, because of its ideal comparative points, will be a useful evaluative tool for current and future emerging technologies.

Author 2 and Author 1 (Under Review) proposed a new protocol for targeting inequality in socio-technical governance. This new protocol combines critical insights from undone science and undone technology, with the ladder of inclusive innovation (Heeks et al. 2013; Heeks, Foster, & Nugroho 2014). Below we further develop and expand this new protocol by suggesting three strategies for those engaged in science and technology governance upstream, midstream and downstream (see Figure 1). For each strategy, we ask several questions based upon Heeks' (2014) ladder of inclusive innovation, and, the following concepts from the undone science and undone technology literatures: interested parties, negative non-knowledge, non-producers, chilling effect (scientific suppression), bandwagon effect (scientific bandwagon), blockbuster effect (profit incentive and non-market), ethnocentric effect (epistemic exclusion), user identity bias (I-methodology and non-users), immaterial non-artifact. When deployed, these strategies build a three part evaluative case study that shines a spotlight on existing inequality and how it is being addressed (or neglected) to create inclusive innovation.

Evaluative Case Background

To start with, the case study must define the science or technology under discussion:

1. What is it?
2. Why is it promising or beneficial?
3. Describe its history in more detail.

Strategy 1 [upstream]: ***uncover*** the unexamined inequality before, or while a new innovation is proposed or marketed

The first strategy is for innovations at the very early proposal stage, or the very late marketing stage (as these stages are very interdependent in most modern corporations).

4. How is the blockbuster effect part of the technology's historical development (Author 2 and Author 1 Under Review; Author 1 2017)?
5. Which powerful interests care about this non-knowledge (Author 2 and Author 1 Under Review)? Alternatively, what non-artifact has been deliberately neglected by technology producers and what was their rationale for creating this non-market (Author 2 and Author 1 Under Review; Author 1 2017)?
6. Who are the technology users and non-users (Author 2 and Author 1 Under Review)?
7. Who are the science or technology producers and non-producers (Author 2 and Author 1 Under Review)?
8. During upstream socio-technical governance, is a bandwagon effect or ethnocentric effect present (Author 2 and Author 1 Under Review)?

Strategy 2 [midstream]: ***maximize*** the inclusion of marginalized communities in the innovation process during research, design, and development

Strategy two focuses on socio-technical governance's midstream phase, where the science or technology is being researched, designed and developed. Our questions draw upon level 4 of Heeks et al. (2013)'s ladder of inclusive innovation combined with insights from undone science and undone technology:

9. Are members of the marginalized group involved with any high-value, upstream and midstream, sub-steps in the technology value-chain, that is, invention, design, or development (Heeks et al. 2013, 5)? Alternatively, how does a marginalized science or technology non-user become a user? Alternatively, how does a marginalized science or technology non-producer become a producer?

10. During midstream socio-technical governance, is an ethnocentric effect or chilling effect present (Author 2 and Author 1 Under Review)?

Strategy 3 [downstream]: ***evaluate*** equity of tangible outcomes after a new innovation has been produced and distributed,

The third strategy is about downstream socio-technical governance when science or technology is produced, distributed, and adopted. This final strategy relies heavily on the concept of normal science, and the heuristic of the inclusive innovation ladder:

11. During downstream socio-technical governance, is a chilling effect suppressing the innovator (Author 2 and Author 1 Under Review)?
12. Did the innovators intend to serve a marginalized community, if so then whom (level 1; Heeks et al. 2013)?
13. Did a marginalized community consume the innovation (level 2; Heeks et al. 2013)? Alternatively, is a marginalized group restricted from utilizing this knowledge or technology by their inability to pay to access, license or buy the research results or technology (Author 2 and Author 1 Under Review)?
14. What was the innovation's absolute impact on the marginalized community (level 3; Heeks et al. 2013)?
15. What was the innovation's relative impact on the marginalized community (level 3; Heeks et al. 2013)?
16. Are members of the marginalized group involved with any low-value, downstream, sub-steps of the technology value-chain, that is, production, or distribution (level 4; Heeks et al. 2013, 5)?
17. How were opportunities for marginalized community members designed and controlled, and do these opportunities represent structural inclusion or post-structural inclusion in the ladder of inclusive innovation (Heeks et al. 2013)?

METHODOLOGY

To demonstrate the utility of the targeting inequality protocol, we use it to evaluate inclusivity mainstreaming in two empirical cases. We collected the empirical data for these cases in our earlier work which we re-examined to generate new insights (Author 1 2017; Author 2 2016).

Case 1 is based upon Author 2's study of 3D printing in the USA, Kenya and Brazil. The projects in the USA and Brazil each included dozens of interviews with experts in the field. Data from the 2013 Digital Inclusion Survey was used to analyze 3D printer adoption throughout public libraries in the US, and the relationship between community wealth and 3D printer adoption. The US librarians were selected to interview through a stratified random sample. Experts on 3D printing in Brazil were found through an intensive literature review. Because it is on an emerging industry, this case is very useful for demonstrating how the targeting inequality protocol can predict potential problems and bottlenecks upstream and midstream likely impacting the creation of innovation downstream that benefits the marginalized.

Case 2 is based upon Author 1's study of community ophthalmology. This case started as a larger study where 82 participants were interviewed from 2009-2012 (Author 1 2019). Collecting data for this case involved purposive and snowball participant selection, where participants were approached by email first. The 11 participants in this case were interviewed face-to-face in their workplace, Aurolab (Madurai, India) or Tilganga-FHIOL (Kathmandu, Nepal). The interviewees were all south Asian men in leadership positions in Aurolab and Tilganga-FHIOL. Each interview was conducted according to a semi-structured interview questionnaire. The interviews were audio recorded and transcribed by Accentance, Inc. (Chantilly, Virginia, USA). Data from the interviews was arranged chronologically and by object conflicts (Hess 2005) to arrive at a case study for intraocular lenses. Since this case is based on new, non-profit innovators in an established industry, it is useful to demonstrate how the targeting inequality protocol highlights how innovators surmounted (or lost) challenges and problems upstream to create more inclusive innovation midstream and downstream.

CASES: TARGETING INEQUALITY IN RESEARCH AND INNOVATION

In the cases below, the targeting inequality protocol offers points of reflection for changing scientific research problem selection and technology design to offer more equitable and just knowledge and artifacts for marginalized peoples. The protocol can also evaluate the degree to which a science or technology is inclusive. To demonstrate how the targeting inequality protocol works to interrogate inequality and mainstream inclusivity in these two cases studies, they are each organized as follows: first, we give the new technology's background and, second, we answer questions for each of the three strategies.

Case 1: 3D Printing in the US, Kenya and Brazil

Additive manufacturing, more commonly known as 3D printing, is an alternative manufacturing technique using computer models and an ink head to print out a structure by stacking material layer by layer. Over the past five years, 3D printing has received more attention as the next revolutionary technology. Economists predicted the 3D printing market would increase 45% a year (Canalys 2015), public intellectuals are explaining how the technology will change the economy (Rifkin 2012), and world leaders predicted this technology could transform old manufacturing towns into production centers (Obama 2013).

Additive manufacturing (3D printing) has at least three advantages over traditional manufacturing. First, additive manufacturing allows designers to create objects which are impossible to create through subtractive practices (Lipson and Kurman 2013). For example, it is possible to 3D print an object with internal moving parts without opening or drilling into the external casing. The designs for 3D printing can easily be tweaked to suit the user's needs, offering another advantage (Lipson and Kurman 2013). Second, it is difficult to make a customized product in traditional manufacturing because assembly lines are designed to produce the exact products quickly and cheaply. In contrast, 3D printing allows consumers to change the design and simply print another object. Easy, cheap customization could lead to on-demand products and spur experimentation and innovation. Rather than using a pre-made product, consumers can create their own product to fit their needs. Alongside customizing objects, a third advantage is the potential of 3D printers to reshape the supply chain. In today's global economy, products are shipped around the world to be manufactured and distributed. 3D printers will allow customers to simply download and print the design from their homes. Instead of requiring shipping containers, ports, roads or stores to supply various products, there is the potential for needing only the 3D printers and the raw materials to feed them (much of which may be sourced locally, or from recycled waste).

3D printers were first developed in the 1980s, so they are not a recent technology. However, the first companies made and sold 3D printers for a market of large corporations. The early 3D printing companies built giant machines used mostly for prototyping expensive industrial parts. Their patent protections meant the technology stayed very expensive and there was little novelty. The early technology developers had tunnel vision about the potential market for 3D printing. By only looking towards corporate sales, they stifled innovation and prevented the technology from spreading to non-industrial and low-income consumers. The patents exemplify creating non-producers of undone technology (Author 1 2017). In this case, patent monopolies prevented early innovation in 3D printing in the global south. As a consequence, the initial introduction of 3D printing to Brazil illustrates getting undone technology done.

Once many key 3D printing patents expired in the 2000s, there was a flood of novelty (Schoffer 2016). New companies started making cheap 3D printers based on expired patents and the tinkerers developed open source printers, like the RepRap. At first much of the innovation was in wealthy countries, but innovators in lower income countries quickly got involved. The small consumer printers developed in the USA were still out of reach for most consumers in low/middle income countries due to the cost and the challenge in getting replacement parts, so innovators in those countries developed their own 3D printers. In Brazil, several 3D printer firms, like Metamaquina (Author 2, Alcantara, & Silva, n.d.), were started and, in Kenya, young innovators built 3D printers out of electronic waste ("AB3D Printing" 2016). If 3D printing had been blocked by price-gouging normal science, then these innovations would not have occurred.

Strategy 1: uncover unexamined inequality

The undone science and undone technology scholarly lens can be used upstream to explain how the potential impacts of 3D printing are constrained, how marginalized groups are excluded, and whether this is an intentional process by elites in Author 2's (2016) description of 3D printing in Kenya.

Undone science and undone technology asks what problem does the global 3D printing industry solve, and whose interests are served by solving these problems? Individuals and corporations are participating in the 3D printing industry. Individual users and producers are predominantly young (23-34 years), STEM educated men who trained in wealthy countries (Thimmesch 2015).

Other questions incited by the concept of undone science include: are the scientific processes, and material choices for 3D printer R&D replicable everywhere? If they cannot be replicated, then can users easily source these materials (Kleinman 1998)? In a parallel example, a critique suggests lab-on-a-chip machines require less skill to operate, but also more expensive company-branded chemicals in comparison to the older, bulkier sequence of Polymerase Chain Reaction machines and spectrometers that fulfill the same purpose (Malkin 2007, 581). There might be a similar critique of 3D printers which offer unparalleled individual creativity and flexibility, but may require expensive, hard to access materials to keep working. It is possible the cost to circulate these materials and components, which often are coming from outside of Africa, exclude certain non-users from participating.

Along those lines, undone science and undone technology also asks: is the global 3D printing industry avoiding the creation of 3D printer designs that serve underserved user groups? Also, which people in what countries do not have the infrastructure to also participate in 3D printer production? The 3D printing industry does not appear to be deliberately blocking or restricting individual access to 3D printing equipment. Instead, Author 2 (2016) finds many libraries purchased 3D printers so the public would have access to them. Public libraries are designed to be open access points to knowledge where people, regardless of status, can access and learn information. More recently, citizens in public libraries can access key technologies like computers, digital cameras and tablets (Jue et al. 1999). If a public library is successful in its mission, then the access to knowledge will be democratized. Therefore, this was a laudable intent to keep access to the new knowledge and equipment of 3D printing unrestricted.

If the library 3D printers increase diversity (e.g., class, race, gender, etc.) among users, that would signal increased inclusivity in the innovation process, the change of non-users into users and, possibly, the change of non-producers into producers.

Undone science and undone technology asks whether the global 3D printing industry is pricing out smaller competitors in less economically developed countries. This would be the expected way for large companies to block technology production and create non-producers. Instead, new companies in Kenya are circumventing international patent law. These Kenyan companies use appropriation (Author 1 and Author 2 2012) by cannibalizing electronic waste from old computers to create the new 3D printers. Thus far, neither international trade regulations, nor national commerce, nor other national regulations are preventing this appropriation work. The result is a new addition to the 3D printing industry, one which also contributes to the recycling and re-use of electronic waste. From the critical perspective of undone science, it is encouraging that the Kenyan companies have not been prevented from building a 3D printing business around electronic waste. The lack of regulation enforcement provides a necessary flexibility in the local innovation system at early stages of research, design, and development.

The undone science theoretical framework suggests the 3D printing industrial culture could be investigated epistemologically. Scholars might consider what sorts of flexible, individually tailored, small, and non-durable products are enabled through 3D printing versus traditional manufacturing. Furthermore, policy-makers could think ahead to the future consequences of 3D printed products over traditionally manufactured products; this gets at the underlying scientific culture and societal values that 3D printing enables in comparison to traditional manufacturing. Systematically considering the underlying knowledge system and associated values of 3D printing might allow for further insights and suggest their policy implications for upstream agenda-setting.

Compared to other technologies, there is less upstream governance of 3D printing because there is such an open source mentality in the 3D printing culture. High level government officials have discussed 3D printing's potential to transform economies, so the technology is expected to receive substantial support upstream. This support will likely cause bandwagon effects where researchers and scholars will chase 3D printing funding.

Strategy 2: maximize inclusion

At midstream of socio-technical governance, there is a greater emphasis on including marginalized people in high-value innovation processes such as research, design and development. Author 2 (2016) claims 3D printing cannot truly address inequality and poverty without governmental support through policy initiatives; otherwise engineers, corporations and other elite groups retain their privilege. However, Author 2 (2016) also finds that poor and uneducated groups do not fully engage with 3D printing. Typically, there is much excitement about the technology when it is first explained. However, as community members begin to use the technology, they quickly discover the challenges with designing useful products using the cheap and accessible 3D printers. A few problems include: it is challenging to create a new 3D design without proper training; the printed artifacts may not be sturdy; and it takes a long time to print the actual part. As a result, novice users fail to use the technology to its fullest extent; many remain non-users.

Despite the challenges, some marginalized groups are involved in the invention, design and development of 3D printers. In both Kenya and Brazil, local innovators are developing new types of 3D printers. In Kenya, AB3D built printers from electronic waste and in Brazil there are many makerspaces and hackerspaces developing 3D printing technology. The challenge is moving the technology from powerful groups within these mid/low income countries to marginalized communities in these countries.

This challenge is complicated by the ethnocentric effects implicated in 3D printing. Even though innovators in Brazil are developing the new technology, many were trained in the USA or Europe. Consequently the epistemological patterns travel with those innovators from their sites of training in the West to the 3D printing culture in Brazil. This implies, on the one hand, that these Brazilian innovators are marginalized on the global periphery of 3D printing as compared to the centered West. Thus they act to counter epistemic exclusion of non-Western perspectives in the 3D printing research, design, and development. On the other hand, these Brazilian innovators are the high-tech elites of Brazil involved in local entrepreneurship around 3D printing in comparison to low-income or other social identity groups in Brazil who do not have such opportunities.

Strategy 3: evaluate equity

Downstream socio-technical governance should include reflection on levels of inclusivity at various stages of production and diffusion (or distribution). Brazilian import regulations epitomize the downstream chilling effect. Interestingly, Brazil often uses these tariffs to encourage local innovation (Aguirre-bastos and Gupta 2009). However, many of the local inventors said the import tariffs made it very challenging for them to get parts to make 3D printers. The import substitution policy is not as strong as in the 1970s and 1980s, yet Brazil still has high tariffs compared to other countries (Goedhuys and Veugelers 2009). Though Brazil wants to encourage local innovation by having tariffs on imported parts, it chills the local 3D printing research.

Author 2 (2016) uses Heeks' ladder of inclusive innovation to identify opportunities for 3D printers to decrease poverty and inequality in the global south. In particular, Author 2 focuses his analysis on challenges African countries will face with using 3D printers to help marginalized communities. Author 2 (2016) points out the level 1 criteria of intent to address inequality is not equivalent to solving the problem of inequality. He describes an example where the intent to serve marginalized communities by placing 3D printers in publicly accessible libraries did not actually meet its goal. Additionally, Author 2 (2016) suggests the level 2 criteria of consumption cannot be used to characterize whether an innovation addresses issues of poverty and inequality, without additionally considering the imbalanced consumption proportions between the marginalized and the elite.

Subsequently, for the level 3 criteria of impact, Author 2 (2016) recommends that impact must be carefully defined to account for technology's introduction to marginalized individuals including both long-term measurement, and a community-based understanding of intended and unintended consequences.

In one sense since the 3D printing innovations are taking place in Brazil, a marginalized community (that is, non-Western) is involved in the low-value, downstream, activities of producing and distributing the technology. However, within Brazil, very few people from marginalized communities are involved in producing and distributing 3D printers. At most, marginalized groups are absorbing and using the technology. The complicated nature of the innovation means inclusivity occurs (and is prevented) on many different levels.

For the level 5 criteria of structure, Author 2 (2016) contends 3D printing is an opportunity for governments, civil society actors, and corporations to discuss the innovation system's structure at different scales. He argues the 3D printing innovation system which is based on patents, higher education, and taxes, currently is not inclusive. This negates the need for discussing post-structural inclusion (level 6 of Heeks et al. 2013).

Next, the second case describes two non-profit technology companies which haves begun to reach high levels of inclusivity in their efforts to eradicate blindness due to preventable causes.

Case 2: Intraocular lenses in India and Nepal

Intraocular lenses (IOLs) are similar to the natural lens which focuses light onto the back of the eye. When cataract disease obscures the natural lens, an ophthalmologist will surgically remove it, and replace it with a plastic intraocular lens. The acrylic intraocular lens was first invented by a British ophthalmologist in the 1940s; starting in the 1980s, it was a regular practice for ophthalmologists in the US and UK to insert IOLs into patients blind due to cataract disease (Author 1 2019 citing Metcalfe, James and Mina 2005).

Three features made IOLs more promising in comparison to the previous technology standard, aphakic "cokebottle" glasses (Author 1 2019). First, the intraocular lens made it viable for ophthalmologists to operate on one eye at a time. Aphakic glasses worked best as a post-surgical visual aid when utilized for both eyes. Therefore, patients had to wait for vision in both eyes to deteriorate due to cataract disease before even one eye could be operated upon. Second, the intraocular lens provided better post-surgical vision than aphakic glasses, that is, the patients had better peripheral vision. The third reason why introacular lenses were considered more beneficial than apahkic glasses is because they were implanted biomedical prosthetics. As such, an intraocular lens could not accidentally be lost or broken. Aphakic glasses, on the other hand, could break, leaving the patient functionally blind again (Author 1 2019).

Establishing Aurolab and Tilganga-FHIOL went against an ethnocentric, Western worldview that thought companies in developing countries could not create reliable, bio-compatible ophthalmic devices (Author 1 2019). Avoidable blindness affects 39 million people around the world. Fifty percent of avoidable blindness is caused by cataract disease. Yet, IOLs produced by multinational companies such as Alcon (Novartis) were priced above the average Indian monthly wage (Author 1 2019).

Aurolab started in 1992 in the southern state of Tamil Nadu and quickly began to provide reasonably priced IOLs to Indian patients undergoing cataract surgery (Author 1 2019). It was among the first ophthalmic consumables company in India (Author 1 2017). Tilganga-FHIOL began in 1993 and produced its first IOLs in 1994 (Author 1 2019).

The case of intraocular lens manufacturing in India has been previously conceptualized as bottom of the pyramid innovation (Prahalad and Hart 2002). This is because the marginalized community is a non-market of impoverished people. This case could alternatively be conceptualized using appropriate technology choice (Willoughby 1990), because of the emphasis on endogenous entrepreneurship to meet local technology needs. However, using the targeting inequality protocol provides a broader lens for evaluation.

Strategy 1: uncover unexamined inequality

At the upstream phase of socio-technical governance, the concepts of undone science and undone technology help explain how Aurolab and Tilganga-FHIOL are examples of civil society organizations serving a new market, with new users while becoming technology producers.

At first, as multinational companies chased the next big blockbuster invention in IOLs, they were willing to donate their unsold, less popular inventory to ophthalmologists in the global south. Eventually, as the market for IOLs became saturated, the multinational companies wanted to have the margins on less popular inventory, therefore they stopped donating the less popular lenses so they could sell them (Author 1 2019). There was no source available for low-cost IOLs. Low-cost IOLs for low-income blind people was an undone technology. Low cost IOLs were immaterial, that is, while multinational companies could have chosen to develop very inexpensive IOLs for very low-income patients, they chose not to.

In the late 1980s and early 1990s, the cheapest IOLs were still too expensive for the average worker in the global south. The high cost of IOLs, combined with the opportunity and travel costs of free cataract surgery, meant surgically corrected sight was not feasible for many low-income Indian and Nepalese blind patients (Author 1 2019). In the US, old inexpensive acrylic lenses cost $200 USD; meanwhile, new foldable, accommodating and other IOL designs costs hundreds of dollars more. Aurolab and Tilganga-FHIOL used turnkey technology transfer to develop their own laboratories in India and Nepal, followed by reverse engineering to create inexpensive IOLs (Author 1 2019). The target price was $10 USD for Aurolab IOLs and $4 USD for Tilganga-FHIOL IOLs.

Before they created their own laboratories, they encountered both a chilling effect and an ethnocentric effect. Western experts claimed that pursuing IOL manufacturing was reaching beyond the capabilities of developing countries (ethnocentric effect). These Western experts opined individually and also collectively through the official WHO 1986 report on cataract management (Author 1 2019). Local Indian ophthalmologists were likewise concerned that creating a new, local, manufacturing laboratory would result in low quality IOLs in the local market (ethnocentric effect; Author 1 2019). The World Bank agreed with the WHO. Meanwhile, the Indian government agreed with the World Bank, a prominent funder of India's National Program for Prevention of Visual Impairment and Control of Blindness (Author 1 2019).

In addition to experiencing the ethnocentric effect from the WHO, the founders of Tilganga-FHIOL in Nepal experienced a chilling effect. Local Nepalese ophthalmologists tried to discredit Tilganga's primary founder as he was seeking funds and approval from His Majesty's Government to authorize a new intraocular lens laboratory. Ultimately, Tilganga relied upon local Nepalese businessmen, a New Zealand ophthalmologist, an Australian NGO, and the Australian government for the funds to create both the eye institute and the IOL manufacturing laboratory (Author 1 2019).

Early funding helped Aurolab develop a regional market for their IOLs. Although the Indian government did not directly support Aurolab, their blindness control program provided funds for training and re-training ophthalmologists in advanced surgery techniques including IOL implantation. Aurolab profited from some of these educated ophthalmologists electing to purchase Aurolab lenses instead of multinational company branded IOLs for their Indian patients.

Finally, no bandwagon effect was present.

Strategy 2: maximize inclusion

At the midstream phase of socio-technical governance, experts (e.g., engineers and medical physicians, etc.) work on high value innovation processes such as invention, research, design and development. Heeks et al. (2013) was interested in how these innovation processes might be made more inclusive. One mechanism of inclusion is to broaden the diversity of experts by ensuring people from marginalized communities are involved. In the case of IOLs in India and Nepal, this is present at two scales: On the international stage there were many non-western experts and users involved in the projects. On the national stage, this case demonstrates greater inclusivity as many of these non-western experts were born in rural villages in South Asia, and were therefore highly focused on providing eye health care to these areas because of their desire to give back to their own communities. As in many countries around the world, folks from rural areas tend to be overlooked by urbanites from high-tech city centers. On the local stage this case does not demonstrate grater inclusivity: the non-Western experts were, with a few exceptions, college-educated, upper and middle class, men of higher caste.

Aurolab and Tilganga-FHIOL were both non-producers that became endogenous technology producers in the respective countries of India and Nepal. Tilganga-FHIOL focused on producing low-cost IOLs, and creating access to low cost ultrasound equipment for cataract surgery (Author 1 2019). Aurolab has additionally moved up the global value chain of invention to conduct research and design (midstream processes). India has well-established biotechnology industry, yet it mostly manufactures generic drugs for sale in the global market (Author 1 2017). Aurolab went from non-producer to producer by: (1) being among the first ophthalmic consumables manufacturers in India; (2) relying, in part, on Western companies to do the expensive, high value, research and development which they reverse engineer to create their own branded products to meet the needs of local, marginalized groups; (3) manufacturing original product designs for sale under Western brands; and (4) researching and developing novel orphan drugs to meet the needs of local, marginalized groups (Author 1 2017).

Before Aurolab was created, there was little infrastructure present to create the tools, instruments, drugs, biomedical prosthetics, and other ophthalmic consumables at low cost for poor blind patients in less economically developed countries. Aurolab is large by volume, but not by profits, when compared to other multinational ophthalmic companies such as Alcon. After starting with small batches, Aurolab had to quickly grow to become a large technology producer to best combat the indifference of existing governments and large technology producers in the global biomedical industry towards poor, disabled consumers. This is because the non-market of non-users (blind poor) in India and around the world is quite large (as described below). Later Aurolab branched out to create other non-artifacts for poor, blind, rural patients. This includes a novel glaucoma drug that does not require refrigeration and a novel intraocular lens design that prevents post-surgical complications (Author 1 2017).

During research design and development, no further ethnocentric effects or chilling effects were present.

Strategy 3: evaluate equity

Evaluating Aurolab and Tilganga-FHIOL downstream in socio-technical governance reveals they are developing and disseminating inclusive innovations. First, Aurolab and Tilganga-FHIOL demonstrate Level 1 on the ladder of inclusive innovation: intent to serve marginalized communities. Since it is a subsidiary of a larger non-profit charitable trust called Aravind Eye Care System, Aurolab has always minimized its profits in order to keep product prices low and maximize how many blind patients it serves

(Aurolab n.d.; Author 1 2017). Tilganga-FHIOL is likewise organized as a non-profit with an important mission to provide low-cost consumables and instruments.

Aurolab and Tilganga-FHIOL use a combination of technology transfer, design and development to provide high quality, high technology to patients at low cost (Author 1 2013, 2017, 2019). They deliberately maintain low profit margins and focus on making medical products more accessible to the blind poor around the world. Both Aurolab and Tilganga have established reputations for providing inexpensive and high-quality ophthalmic consumables and instruments while partnering with other (primarily non-profit) organizations that supply their products to marginalized communities around the world.

Second, the technology developed by Aurolab and Tilganga-FHIOL has clearly been utilized by marginalized communities; this addresses Level 2 on the ladder of inclusive innovation, consumption (Heeks et al. 2013). Aurolab and Tilganga-FHIOL serve technology non-users in a marginalized community of rural and urban blind poor in less economically developed countries around the world. In India in 1989, this non-market included 12 million blind people; of those, 80% were blind from cataract disease (Author 1 2019).

In 1999, Aurolab was the first Indian IOL manufacturer to get the CE mark (certifying their product for consumption in the European Union); they sell to 130 countries around the world, primarily to other LEDCs (Aurolab n.d.; Author 1 2017, 2019). Aurolab's nylon and silk sutures, which received US FDA approval in 2003, are sold in the US under another company's brand name. Tilganga-FHIOL lenses are sold in other LEDCs and also Australia. In 2012, Tilganga-FHIOL lenses were the only Nepalese product with the CE mark; they have had this certification since 1998. Tilganga-FHIOL lenses also have the Australian Therapeutic Goods Administration (TGA) certificate. Tilganga-FHIOL was the first Nepalese company to attempt to meet ISO 9001 quality assurance standards. Interesting from a cost engineering standpoint: Tilganga-FHIOL lenses are individually checked (a high labor cost), not batch checked (a low labor cost), where individual checks arguably yield higher quality lenses.

Thirdly, there is positive impact both absolute and relative (see Heeks et al. 2013). While Aurolab and Tilganga-FHIOL are not the only low cost ophthalmic consumable and equipment manufacturers in the world, they, along with FHIOL-Eritrea are among the only three non-profit ophthalmic consumable and equipment manufacturers globally. The absolute impact occurs through increased consumption of IOLs, and thus increased cataract surgeries worldwide. The managing-director of Aurolab, "Sriram D. Ravilla explains, 'We sell 7 to 8 percent [of the IOL global sales volume] so we should make 80 to 90 million U.S. dollars, but our IOL division made less than 10 million U.S. dollars. We priced it that way' " (Aurolab n.d.; Author 1 2019, 169). In addition to IOLs, Aurolab has expanded their manufacturing to create other inexpensive tools, equipment, consumables, and drugs for use by ophthalmologists and their low-income patients. Aurolab's growth is well-supported by the market of non-users transformed into users; other non-profit and for-profit eye surgical clinics around the world purchase Aurolab's goods for their poor blind patients. Aurolab’s primary customers are non-profit organizations fighting avoidable blindness among the poor around the world. Likewise, Tilganga-FHIOL's primary customers are also other non-profits: Nepal Netra Jyoti Sangh (Nepal), Christian Blind Mission (Germany) and SEVA Foundation (USA).

Aurolab and Tilganga-FHIOL are part of implementing the joint World Health Organization-International Agency for the Prevention of Blindness (IAPB) Vision 2020 program. In a report commissioned by the Fred Hollows Foundation, IAPB, Sightsavers International, Light for the World, CBM International, and Operational Eyesight Universal, PriceWater Cooper says, "In developing countries, we estimate the total benefits [of Vision 2020] to be at least $517.1 billion (2009 USD) over the ten years from 2011 to 2020, significantly outweighing the additional investment required ($128.2 billion 2009 USD), a benefit cost ratio of some 4.0 times the cost"(Fred Hollows Foundation 2013, 4). This additional absolute impact increases funds spent on eradicating and preventing blindness.

The relative impact occurs through decreased projections for future blindness rates worldwide, and increased projections for better livelihoods (with fewer years lost due to ill-health, disability or early death) worldwide. "Benefits that were not able to be quantified due to a lack of supporting data that have been analysed [sic] qualitatively include increased primary education, reduced extreme poverty, increased independence, self esteem and improved social networks and increased gender equality"(Fred Hollows Foundation 2013, 9).

For Level 4, inclusion in the innovation process, Aurolab's production facility employs marginalized Indians such as: low income women, persons of non-Hindu faith, and individuals with disabilities (deaf and mute women). The production jobs (downstream process) give Aurolab employees the opportunity to make a good income while working to benefit society. Aurolab finds that university graduates apply for production positions, however, Aurolab primarily hires women with high school diplomas. However, there is a limit to marginalized community members' inclusion in R&D and management, as, with a few exceptions, it is rare for a person on the production line to move up through the ranks of the company.

In contrast, Tilganga-FHIOL, which employs educated urbanite men and women from Kathmandu on their production line, might consider how to seek out, train, and employ more marginalized people.

Finally, there is some limited evidence of level 5, structural inclusion, and level 6, post-structural inclusion. At level 5, Aurolab and Tilganga-FHIOL are changing the market for innovations by revealing both the economic and social value of developing medical products for marginalized communities. Through their efforts, there are new business models to develop technologies for marginalized populations. At level 6, Aurolab and Tilganga-FHIOL are changing the perception of innovation's geo-political location. They demonstrate that innovation does not only take place in wealthy countries and it is possible for innovations to move from low income countries to high income countries (Author 1 2013; Author 1 2019).

Discussion

Evaluating 3D printing with the targeting inequality protocol demonstrates potential problems and bottlenecks upstream and midstream. Upstream socio-technical bottlenecks identified by local entrepreneurs in Brazil and Kenya include the type and cost of materials and patents that impact both 3D printer design, and economic viability of sustained 3D printing. Inclusivity bottlenecks include determining the methodology, beyond public libraries, to transform marginalized communities within countries in the global south into users of 3D printers. Becoming a user of 3D printing requires specific levels of education and skill despite 3D printing's promise of flexibility and straightforwardness. However, many marginalized non-users in the global south are disadvantaged by less education and little experience with technology in comparison to existing Western users. The original creators of 3D printing ignored this education and experience gap creating user identity bias. Therefore, new methods (likely borrowed from community engagement participatory methods) should be implemented downstream to transform marginalized non-users into 3D printing users.

Evaluating IOLs with the targeting inequality protocol demonstrates how innovators surmounted (or lost) challenges and problems upstream to create more inclusive innovation midstream and downstream. Many (Western and South Asian) medical scientists' expert opinions were based in an ethnocentric worldview which, unfortunately, biased them against the capabilities of their non-Western peers to develop risky high-technology in South Asia. This meant they set up roadblocks against these novice innovators for arbitrary reasons. However, these novice innovators transformed themselves from users to producers of IOLs while maintaining an emphasis on serving marginalized communities. This emphasis meant they were thoughtful about integrating diverse perspectives and people throughout their design, development, and production processes. These two non-profit technology companies illustrate how to create inclusive careers and inclusive products for marginalized communities.

When writing the two cases, it was our experience that utilizing the protocol helped to draw out insights we had not previously considered. For example, protocol strategy 3, when applied to the case on intraocular lenses in India and Nepal, highlighted a positive downstream process: the involvement of marginalized people, specifically women and disabled people, in the producing products for other marginalized people, that is, rural poor blind people. This insight was not uncovered in earlier analyses such as Author 1 (2017; 2019).

In another example, protocol strategy 1 suggested questions for the emerging 3D Printing industry in the US, Kenya and Brazil that might be thoughtfully considered during upstream socio-technical governance, but, as yet, do not have empirical answers. These questions predicted the potential blocks that powerful interests might construct. As the old Latin proverb suggests "forewarned is forearmed" for visionaries interested in creating more inclusive innovation. Therefore, it seems the targeting inequality protocol, with its three strategies, is useful for building an evaluative case that can both forewarn of potential problems, and, demonstrate potential actions to solve historical problems in creating inclusive innovation. This makes the targeting inequality protocol a useful addition to socio-technical governance upstream, midstream and downstream in the innovation process.

A major limitation in this research is our failure to interrogate the starting assumption of socio-technical governance: science and technology's positive role for enhancing society, especially in marginalized communities within the global south. The relationship between science, technology and international development is complicated, especially because it is intertwined with postcolonial relationships between states with uneven access to resources (Cherlet 2014; Shrum 2015; Bauchspies 2014). Typically, the "adoption of a new technology selectively creates new absences and presences that are shaped by existing social relations" (Bauchspies 2014, 65; Winner 1980). Future work might include challenging this starting assumption and rigorously defining circumstances where addressing inequality between elite and marginalized groups does not require science and technology innovation. Likewise, future policies for development may require a more thoughtful look at what innovations are already present locally, and from there extrapolating how science as a social institution can aid in appropriating science and technology to best fit local needs and visions for the future (Bauchspies 2014; Author 1 and Author 2 2012).

CONCLUSION

In summary, our goal was to make a tool to highlight inequality in ongoing and completed science and technology innovation processes. To that end, we developed a new protocol to mainstream discussions of inequality and inclusivity in socio-technical governance. We utilized the socio-technical governance stream metaphor which has interesting actions, points of feedback, and reflection points upstream, midstream, and downstream (Fisher, Mahajan and Mitcham 2006). Next, we described six problems that generate inequality which occur primarily upstream and midstream during socio-technical governance of innovation: the infrastructure problem (scientific bandwagons upstream creates non-knowledge), the powerful interests problem (chilling effect midstream and downstream creates non-knowledge), and the Eurocentric worldview problem (ethnocentric effect upstream and midstream creates non-knowledge), price-gouging problem (blocked access to normal science downstream), profit incentive problem (emphasis on the next blockbuster invention creates non-artifacts upstream), the privileged user problem (user identity bias creates non-users midstream). Five of these six problems that generate inequality in innovation are typically co-constructed with ignorance and negative non-knowledge or non-artifacts. The ladder of inclusive innovation is a useful heuristic to evaluate the equity of outcomes while science and technology is being researched, designed and developed (midstream) and after science and technology has been produced and distributed (downstream). The "targeting inequality" protocol uncovers six problems that generate inequality (which is forward looking), and also evaluates inclusivity with a heuristic tool (which is backwards looking). Altogether, this unique protocol can uncover problems, evaluate outcomes, and suggest actions with the end result of inclusivity mainstreaming socio-technical governance.

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