Draft Report

Workshop on Research Agendas in the Societal Aspects of Synthetic Biology

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Executive Summary

Introduction

There is broad agreement even among science and engineering institutions that societal research is crucial for the responsible development of synthetic biology. In response to this need, on 4-6 November 2014, in Tempe, AZ, a workshop was held to help explore and articulate research agendas in the societal aspects of synthetic biology. The workshop gathered approximately 115 interdisciplinary participants to generate, articulate, and disseminate ideas for research on the societal aspects of synthetic biology.

About the Workshop

The U.S. National Science Foundation (NSF) funded the workshop through its Engineering Directorate, with the assistance of the Life Sciences and Social, Behavioral and Economic Sciences Directorates. The principal investigators (Guston [ASU], Murray [Caltech], and Brian [ASU]) circulated invitations and pre-conference surveys that included opportunities for both substantive and procedural input. The workshop ultimately attracted more than 50% beyond the initially expected number of participants, who engaged in two days of plenary and breakout sessions, including detailed discussions of a dozen research areas within the societal aspects of synthetic biology.

Research: Areas, Style and Scale

The initial proposal identified twelve areas of societal research on synthetic biology; our pre-survey invited other suggestions. The lack of serious objection or addition suggested that we captured the most pressing and interesting areas with reasonable precision. Breakout groups described each of the following research areas: Anticipation & Futures; Bioeconomy; Biosafety & Biosecurity; Governance; Informal Science Education; Research & Innovation Systems Analysis; Responsible Innovation; DIY/Makers; Ethics; Integration & Reflexivity; Public Opinion & Values; and Risk & Sustainability.

A major question, interwoven with that of "what to study?" asks instead "how to study?" Participants asked whether we need a research agenda specifically focused on synthetic biology, expressing significant concern about finding the right balance of integrative and independent social science research. Questions of integration cannot, however, be separated from questions of scale. Absent a large national synthetic biology program, participants nevertheless saw synthetic biology as both inviting and necessitating significant societal research, and they held this opportunity as a step beyond the "ethical, legal and social implications" (ELSI) model, which minimizes the scope of social science work and makes it contingent on scientific funding.

Other Considerations

If the workshop addressed questions of research agendas in the societal aspects of synthetic biology and styles and scale of research, it also identified a set of meta-questions that NSF should consider in arriving at its answers. The most important of these is, "What does NSF want to accomplish with societal funding?" The workshop participants eschewed the most extreme aspects of instrumental motivation and seemed most excited about the possibility of NSF's attempting to support a co-constructed synthetic biology that would develop a truly integrated research program and be a model of responsible innovation. A second important meta-question

is, “What is NSF’s role among the various agencies in supporting societal research on syn bio?” Workshop participants expressed support for a principal role for NSF, given its historic association with high-quality social science research, but they also expressed an expectation that other agencies would support societal research associated with their missions.

Next Steps

Continuing workshop activities include: 1) Circulating this draft report to the entire list of workshop invitees and other select individuals for comments prior to finalizing the final report. 2) Publishing, in February 2015, a special section (edited by co-PI Brian) of the *Journal of Responsible Innovation* featuring 17 “Perspectives” pieces on responsible research and innovation in synthetic biology from workshop participants; 3) Completing a detailed public website with videos, interviews with participants, background papers, posters, notes from the graphic recorder, and short reflections/commentaries on the workshop; and 4) Planning events in Washington, DC to disseminate results to the National Academy of Sciences Forum on Synthetic Biology and other interested groups.

Introduction

On 4-6 November 2014, at the Mission Palms Hotel (near Arizona State University [ASU]), in Tempe, AZ, a workshop was held to help explore and articulate research agendas in the societal aspects of synthetic biology. The workshop gathered approximately 115 social scientists, humanists, scientists and engineers who are working in the area of synthetic biology and related emerging technologies. Through drafting assignments prior to the workshop and an engaging combination of plenary sessions and breakout activities at the workshop, the participants sought to generate, articulate, and disseminate community-generated ideas for research on the societal aspects of synthetic biology.

A recent statement by the IAP (2014) – the global network of science academies – pegs the ability to realize the "global potential" of synthetic biology to meeting the challenge not only of tremendous scientific opportunity, but also of good governance. Of the five explicit recommendations from the IAP (2014, 2), four are directly related to societal research. The IAP is not alone in understanding that societal research is crucial for the responsible development of synthetic biology. The agenda of the US National Academy of Sciences Forum on Synthetic Biology has been steeped in societal issues – in particular risk, intellectual property, and the bioeconomy (see http://sites.nationalacademies.org/PGA/stl/SynBio_Forum/index.htm). While such understanding is helpfully widespread, research, training and engagement activities have been proceeding apace. Both large- and small-scale projects have begun, primarily in the US and Europe, and societal researchers have been active both in their own right (e.g., Kuzma and Tanji 2010) and integrated with such high-profile synthetic biology activities as the International Genetically Engineered Machines (iGEM) competition (Smolke 2009; Brown 2007) and the Synthetic Biology Engineering Research Center (SynBERC; e.g. Rabinow and Bennett [2009]). A modest body of scholarly literature is progressing – with roughly 150 indexed publications through 2013 – along with a growing body of journalism (e.g., Specter 2009; 2012; Garrett 2013), including by scientists (e.g., Lewontin 2014).

Many hail synthetic biology as a highly disruptive and potentially transformative technology. As such, there are numerous important questions outstanding, and the need for a coordinated effort to identify critical areas of research emerged. Societal research – including empirical, theoretic and normative inquiries – can help assure the responsible innovation of synthetic biology by participating in informed discussions of how to define synthetic biology and its related fields, by tracking the history and ongoing state of its development, by creating processes through which different publics can express their hopes and concerns about it, by increasing the capacity of scientists and engineers to be appropriately responsive to such hopes and concerns, and by further developing our understandings of what, indeed, ideas of responsibility must mean in conjunction with increased skill in engineering life.

This workshop convened a large number of active researchers in the field and sought guidance from both the social and the technical perspectives. The workshop contributed to the development of research agendas that are specific to synthetic biology and some that are more broadly applicable to emerging technologies. Participants also contributed to the development of scholarly and professional infrastructure, to strengthen the fields of science, technology and society (STS) and science policy both within the field of synthetic biology and beyond.

About the Workshop

When we invited people to attend the workshop, we circulated a survey asking for substantive information about the topic – What are your research interests? Do you have any current synthetic biology projects? – as well as for procedural input for the workshop – What breakout sessions are you interested in? Would you recommend any other topics? Would you be interested in writing a 2-page background paper and/or present a poster at the workshop? Who else – especially students – would you like to see invited?

We initially expected about 75 participants at the workshop. As word spread, however, and as we received feedback from the initial round of respondents, the invitation list grew to about 150. Of these, 116 people attended from the United States, Canada and Europe. Sixty-nine people contributed background papers for circulation to participants ahead of the workshop, and 17 people presented posters at the workshop. The papers addressed the question "What kind of work ought we be doing?" The posters were an opportunity to present current or recently completed research. Background papers and posters are available on the workshop website, http://cns.asu.edu/synbio.

The workshop started at 5pm on 4 November 2014 and ran until 12 noon on 6 November. It featured a mix of plenary and breakout sessions, the specific speakers at which can be found on the agenda at http://cns.asu.edu/synbio/agenda. The workshop was headlined by ASU President Michael Crow, who spoke to the group at lunch on 5 November about imagining new ways of thinking through the creation of new "knowledge enterprises."

Much of the work occurred in two rounds of breakout groups designed to elicit answers to the question, "What Kind of Work Do We Want To Do?" The topics, the most popular in the pre-workshop survey as identified by the organizers and selected by participants, were: Anticipation & Futures; Bioeconomy; Biosafety & Biosecurity; Governance; Informal Science Education; Research & Innovation Systems Analysis; and Responsible Innovation. The second round included: DIY/Makers; Ethics; Integration & Reflexivity; Public Opinion & Values; and Risk & Sustainability. Two sessions were left open in the second round for emergent topics, and while two topics – curriculum and international & inter-agency collaboration – did emerge, both sessions were under-attended and neither produced a usable summary. While student rapporteurs were provided for most of the groups, organizers asked participants to identify their own discussion leaders to reflect and report back on the following questions:

1. Please summarize in a few sentences the state of this portion of the field.
2. Please articulate the most important existing questions for this portion of the field to contend with.
3. Please identify any major hurdles to answering such questions.
4. Describe how this portion of the field stands in comparison to other portions. Is it more or less important? Is it dependent on others, or are others depend on it?
5. Describe any training or outreach requirements particular for this portion of the field.
6. Please list in a bibliography the most important works in this portion of the field.

The breakout groups reported back over dinner on Wednesday, giving all participants an opportunity to reflect on the breadth of ideas generated.

During the concluding plenary sessions, a group of panelists took turns talking about the kinds of work or organizations they would like to see, and then participants at large wrote their suggestions on large notepads at the front of the room. (These suggestions are described more deeply below.) The final session focused on group brainstorming next steps after the workshop.

Research: Areas, Style and Scale

The workshop activities were designed to elicit opinions about what we ought to be researching and the ways in which we ought to structure those research programs. Here we present the community-generated ideas about key research areas, style and scale. In Appendix A, we attempt to synthesize this rich set of ideas, in what might be used as a template for a request for proposals.

Research Areas

In our initial proposal, we identified twelve different areas of societal research on synthetic biology, and in our pre-survey of invitees asked for other suggestions. There were no objections to these categories or proposals for new ones that could not be integrated into these, suggesting that we captured the most pressing and interesting research areas with reasonable precision. The breakout groups described each research area in distinct and, at times, overlapping ways – understandable since STS and synthetic biology are both complex and fundamentally interdisciplinary. We present brief highlights of the main points raised at each session below.

Anticipation & Futures

Three broad themes emerged: (1) How can we produce and evaluate and "better" synthetic biology futures, where "better" is defined with respect to their social scientific as well as technical plausibility, the inclusiveness of processes through which they were produced, etc.? (2) How can we ensure the broadest possible participation in imagining and shaping futures for synthetic biology? (3) What is the relationship between anticipations and anticipators, or the content and context of anticipations in synthetic biology? Participants differed in their relative interest in the content versus the context of futures. Some participants were concerned about the task of learning more about the future and critically evaluating proffered futures for their plausibility. Others were more concerned with the stakes associated with who has the agency to imagine and shape the future, as well as the politics of hype and hope. Interest in opening up the future of synthetic biology to broader publics was widely shared.

Bioeconomy

Discussions of a bioeconomy research agenda generated significant attention and enthusiasm among participants. Definitions of the bioeconomy vary among countries or organizations. For example, whether or not the bioeconomy includes health-related technologies varies: The US includes health-related technologies in its bioeconomy definition, but most of the EU does not. Participants grappled with what gets included and what gets ignored in discussing a bioeconomy, the mechanisms by which a bioeconomy emerges and flourishes, and, importantly, what gets lost in that transition. There is a significant lack of information and very few sources of data (e.g., participants pointed to Rob Carlson's work as the only data available). The research interests include the history of the term, life cycle analyses of new products, comparative work on imaginative futures, and the bioeconomy in contrast to other forms of economic growth.

Biosafety & Biosecurity

Biosafety and biosecurity are often grouped together and presented jointly as a rough term for the health and safety risks associated with synthetic biology, regardless of their potential origins

in accidents or intentional releases of synthetic organisms through legal or illegal means. However, little has been done to clarify the nature of these risks or specify what comes under biosafety and what under biosecurity. Thus, attendees argued that more work was needed to unpack the relationship between these terms – are they in fact related, or are they separable – and to address risk more broadly. Participants focused on the question, "What are the right conditions for a culture of responsibility in synthetic biology?" They generally agreed that the most pressing issues had to do with infrastructure and regulatory pathways, valuing both quantitative and qualitative approaches to biosafety and biosecurity, and paying attention to biosafety and biosecurity concerns with respect to both products and process.

Governance

Governance, participants noted, is not just about regulations, but it is also about the interaction among different sources of power in society. In the European context, there is significant discussion about the meaning and scope of governance, including its relationship to responsible research and innovation, whereas the US context tends to focus on product regulation and ultimate use. Thus, the importance of comparative governance work emerged as a critical need: Do we have uniform characterizations of the state of governance in various contexts? Should we assume that governance systems are always in conflict because values underlie governance structures? Most generally, participants wondered about whether governance issues could be generalized across emerging technologies, and whether or how we can we apply lessons learned from other technologies – including nanotechnology and even earlier versions of genetic engineering – to synthetic biology.

Informal Science Education

Participants began by noting that the NSF has defined informal science education (ISE) through its grants program as including media, museums, and out-of-school programs, but they argued that ISE should be more inclusive of theatre, broadcasting, and other non-academic institutional activities. They also noted that, relative to other countries, there is little ISE regarding synthetic biology going on in the US. ISE is more than literacy and engagement; it includes a thorough consideration of ethical and societal implications through productions of activities, experiences and artifacts. ISE has substantial research from decades of work focused on understanding science, and it is now moving toward more directly engaging with science. Participants agreed that unpacking the definition of synthetic biology is critical to engagement and to translating language and concepts for both scientists and publics. Key areas of interest include measuring the impact of engagement activities, and creating incentives for scientists to engage in substantive engagements with publics.

Research & Innovation Systems Analysis

Participants agreed that the biggest research challenge for Research and Innovation Systems Analysis (RISA) is developing a definition of synthetic biology that can support research in the area, including research that in turn supports policy. Such a definition needs to capture the variety in the field, while still being able to be operationalized and used for measurement. RISA traditionally looks at publications and patents, but synthetic biology offers other interesting sources and tools, such as examining repositories of plasma and cells and assessing who uses them (via cross-citations of papers and of these repositories) as a measure of knowledge flows. However, these data are not readily available in a structured form, openly accessible on

the Internet, for a reasonable price. This challenge is also an opportunity for tool creation and education; however, well-designed tools depend on rigorous and accessible social science research.

Responsible Innovation

Responsible Innovation (RI) is an umbrella term encompassing themes of risk management, uncertainty avoidance, technology assessment, and more. It is a metaphor that allows different actors to frame the term according to their own experience. The criteria by which something gets labeled "responsible" also varies depending on desired outcomes. Participants noted that scientists and researchers are a valuable resource as we try to establish more clearly articulated societal design criteria, expand the solution space and make choices more explicit or transparent. A significant portion of the conversation focused on this question of embeddedness: How can innovation systems internalize RI processes as distinct from regulatory oversight?

DIY/Makers

The study of DIY bio as a movement has been a lightening rod in the field, and participants lamented the significant hype in the media. DIY bio is a fragile area, in that there are a small number of people active in the field and costs are prohibitive, although there are several sources of income, such as crowdfunding and lab fees, to support maker labs. Participants focused on the need to better understand how labs are established and then how to best evaluate and learn from the labs, the links between maker labs and museums, and the ways in which maker labs can help structure or create better conversations about synthetic biology. Despite attention from media, public agencies, and some scholars, there remains disparate understandings of the capabilities and potential of DIY bio.

Ethics

Significant work is needed to make the necessary connections between science and ethics, and between scientists and ethicists, more substantive. One of the exemplary questions participants opened with was, "Is it ethical to describe a technology as revolutionary and then say that no new regulations are needed?" This question underscores the importance of understanding what gets designated as a question of ethical concern, in other words, what gets to count as a question with ethical content, as opposed to or in addition to a question with scientific content. Since many talk about synthetic biology as a disruptive or transformative technology, participants emphasized the need for close ethical attention to whose interests are prioritized in its development, e.g., who is benefiting and who is suffering from the disruption or transformation.

Integration & Reflexivity

Integration is bringing together diverse people to create a landscape of different perspective in such a way that differences fit together and are complementary. Integration is a means to enhance reflexivity, which is self-critical reflection on the assumptions and meanings that are embedded in the work one is doing. Reflexivity generates humility and enables action. Integration and reflexivity can be resources for (1) social science research and for (2) broadening core science and innovation processes so that they take diverse social and public values into account. One of the most critical questions that emerged from the group discussion focused on assessment: What evidence is there that approaches to reflexivity and integration make a difference? Studying the conditions (if any) in which reflexivity and integration are mutually

and productively enhanced among synthetic biology researchers and social scientific researchers is important; the potential benefits and trade-offs for participating groups are not well understood. Participants also noted that institutional objectives provide a significant hurdle: There are risks for PhD students, and even established researchers, to involvement in integrative projects because of professional pressures to specialize, institutional sanctions against broader reflection and interaction, the general reality of siloed fields of inquiry, and power differentials among those fields.

Public Opinion & Values

Discussants agreed that the research needed to discover "public opinion" about synthetic biology needs to be detailed and explicit about definitions of syn bio—and delineated six different possible definitions of synthetic biology. The group agreed that it was problematic to do research about public opinion in a way that convoluted six (and maybe other) very different concepts lying within the "syn bio" rubric. To have any opinion, the group argued, the public being contacted would need to know what the applications of the proposed technology were, as information about these is essential for cost-benefit analyses. The group thought the most fruitful areas of inquiry were: how publics *acquire* opinions and values, whether publics see technology as being "special" when "biology" is in the title, and developing a better understanding of why and to what end we engage publics in the responsible development of syn bio.

Risk & Sustainability

Sustainability is a deeply normative concept, one that encompasses much more than risk avoidance. Thus, participants thought it best to separate the two concepts, especially since their respective connections to synthetic biology are so different. Participants agreed that risk should always be considered more broadly. Measuring risk is very challenging, in particular because it is difficult to know on what level to focus, e.g., the individual or some aggregate like the nation, or what temporal dimension is most appropriate. Participants noted that everyone wants publicly funded risk assessments, but companies and NGOs want risk assessments for very different reasons and uses.

Style

A major question from the workshop, interwoven with the question of "what to study?", asks instead "how to study?", that is, how a new research program or programs in the societal aspects of synthetic biology might be structured. Researchers asked whether we need a research agenda specifically focused on synthetic biology; the most important concern was finding the right balance of integrative and independent social science research.

Currently, many social scientists and humanists perform their research in very close connection to the engineers and natural scientists involved in synthetic biology, but there is (naturally) a variety of styles of research, even among those "engaged" or "embedded" with what otherwise would be their objects of study. Calvert and Martin, for example, distinguish between the roles of "contributor" and "collaborator," and emphasize the importance of the latter, who are specialists who "can potentially influence the scientific knowledge that is produced" through a "more genuinely collaborative exercise" (2009, 203). Rabinow and Bennett (2012, 48) distinguish "three modes of engagement": one of "representing experts," a second of facilitating relations between science and society," and a third of "problematization and inquiry" – in which

the final mode aspires to very much the same kind of thing as Calvert and Martin's collaboration, but with perhaps a still-greater autonomy for the social scientists. Fisher's NSF-funded sociotechnical integration projects (STIR; NSF #0849101) are embedded, sustained and open-ended. The desired outcomes are learning, deliberation, and practical adjustments; as such, the focus is on long-term capacity building.

The embeddedness model keeps social science research grounded and real, but in good integrated work, the technical and social sides do not dictate what the other does. Rather, their differences are complementary, and they *open up* new research possibilities through awareness and humility. Participants noted that there are specific mechanisms that can promote the appropriate degree of independence, such as a mechanism in the review process to decline funding for a mostly technical program if it is a poorly integrated embedded project. Embeddedness, participants noted, does not just refer to synthetic biologists, but also social movements and communities that are the "focus" of synthetic biology solutions.

Some participants emphasized the need to build on the important work in NSF's societal network in nanotechnology. A large body of work that emerged from this initiative – on futures, uncertainty, risk, innovation, history of science – that is deeply relevant to synthetic biology. Perhaps more importantly, the model of NSF's support for societal work in nanotechnology allowed teams to focus on large questions and develop unique capacities, tools and data sets – with a critical degree of independence from technical priorities. Within these focused teams and more broadly, the critical importance of leadership cannot be understated. As researchers committed to producing better social outcomes, we have to appreciate all parts of the process. It takes time and space to adequately broker relationships.

Scale

Questions of integration cannot, however, be separated from questions of scale. There was consensus that an organized research program was needed, but there were worries about focusing too heavily on the technology. Absent a large national synthetic biology program, do we need or want a large 'societal aspects of synthetic biology' program? This, participants noted, was an opportunity to shift goals and step away from the "ethical, legal and social implications" (ELSI) model in which the social side is funded only through (as a small percentage of) the technical side. The ELSI model does little to bolster the credibility of social science and humanities researchers, as it both minimizes the scope of their work and makes it contingent on scientific funding. Absent a focus on particular phenomena (such as synthetic biology), however, it is much more difficult to create real, focused partnerships. Facilitating collaboration across disciplines is seen as one of the most important ways NSF can lead.

The workshop participants also agreed on the importance of both large-scale funding ***and*** independent funding for the success of the cooperative and collaborative agendas. This opinion is supported by the successes of the Centers for Nanotechnology in Society (at Arizona State University and the University of California, Santa Barbara), the findings of a study (Rogers et al. 2012) of integration of societal research at NSF-funded Nano-scale Science and Engineering Centers, and Rabinow and Bennett's (2012) own account of their "experiment" with SynBERC. Building on the work started by NSF's nanotechnology societal initiative necessarily involves scaling up, in order to develop new processes, capacities and infrastructure that are not dependent on a particular technology.

Other Considerations

If the workshop was meant to address such strategic questions for a research agenda in the societal aspects of synthetic biology as: "What research questions should NSF be interested in?", "What styles of research should NSF support?" and "What scale of research should NSF support?", it also identified a set of meta-questions that NSF should consider.

The most important of these meta-questions is, of course, "What does NSF want to accomplish with societal funding?" Answers could range from the highly instrumental for a technology such as synthetic biology (e.g., pathways for public engagement of syn bio outcomes), to the highly instrumental for societal researchers (e.g., societal research to best contribute to disciplinary development in STS), to the highly instrumental for policy makers (e.g., societal research to describe syn bio and its potential in objective terms and useful categories). Another dimension of answers include generating knowledge that is highly specific to synthetic biology (however defined), or generating knowledge that might be more generally applicable to interdisciplinary interaction, emerging technologies, or other more general concerns.

The workshop participants eschewed the most extreme aspects of instrumental motivation and seemed most excited about the possibility of NSF's attempting to support a fully and self-consciously co-constructed synthetic biology – meaning developing a fully collaborative enterprise that attempts to equilibrate the power dynamics between the natural science/engineering side of synthetic biology and its social and humanistic side, design a set of research questions well-informed by both societal problem formation and scientific opportunity, and develop a truly integrated research program that would be a model of responsible innovation.

Of course, these answers are not (entirely) exclusive, and in most circumstances societal researchers themselves may have to perform in the register of each in order to make progress on one. That is, the ability to make autonomous progress on a disciplinary agenda, for example, may in some instances be conditioned on instrumental contributions to technology development or policy matters But there are design and funding choices that could be made – particularly with respect to the scale and style of research – that would emphasize one dimension of answers over another.

A second important meta-question is, "What is NSF's role among the various agencies in supporting societal research on syn bio?" In the National Nanotechnology Initiative (NNI), NSF supported nearly all societal research – 85-90% or more – sponsored by the Federal government, despite supporting, ultimately, only about 25% of nano-scale science and engineering research. Given the vast scope of NSE research, the specific applications sought by mission agencies like DOE, DOD, and NIH, and the potential contribution of societal research to inform understandings of the connection of nano to those missions, significant opportunities might have been lost by other agencies' failing to pursue societal research. Then again, the mission agencies do not have as strong a tradition as NSF does in supporting societal research that is well-informed by social science disciplines and innovative in its own right, as opposed to merely instrumental.

Part of NSF's answer to this question might also depend on whether any national initiative emerges around synthetic biology. If so, such an initiative might cast NSF in the NNI-like role of potentially servicing the initiative as whole through its own sponsorship of societal research, or it might delineate better than NNI did societal contributions from various agencies. Workshop participants believed, however, that even absent such an initiative, the questions raised by synthetic biology demand focused and sustained attention from social scientists.

Conclusion and Next Steps

The workshop brought together more than a hundred participants from academia, industry, government and non-profits to generate and articulate a set of research questions for the societal aspects of synthetic biology. While the lists of key questions and challenges are long (see Research Areas, as well as Appendix B), participants were in agreement about a few core ideas. Participants agreed that, even in the absence of a national initiative in synthetic biology, it is important to do societal research on synthetic biology. Many see synthetic biology as having the potential to be a transformative technology. There is thus both the need and opportunity for rigorous social science research to promote responsible innovation.

Participants also agreed that truly integrated research programs would best promote a co-constructed synthetic biology. An integrated (or embedded) research program encourages awareness amongst all groups and opens up possibilities for new research directions. There was considerable agreement that we need to be doing more to collaborate across disciplines and realize the possibilities of interdisciplinary research. As such, participants saw a chance for funding agencies to expand beyond the traditional funding model that sees social science or humanities research as being in service to and dependent on the scientific research agenda. Participants therefore emphasized that different kinds and sizes of support for societal research on synthetic biology, including large-, medium-, and small-scale activities, would best achieve appropriate the combinations of independence and interdisciplinary coordination.

Next steps

The PIs are committed to a broad dissemination of the knowledge generated at the workshop. The agreed upon outputs of the workshop include a detailed report, a special section of a journal, a website, and future events in Washington, DC:

(1) Following submission of this draft report to NSF, we will circulate it to the entire list of invitees for comments. We will incorporate comments into a longer, more substantive final report that will then be made widely available. We hope this document will be helpful to a range of funding agencies looking to fund innovative and integrative research in the societal aspects of science and technology.

(2) In February 2015, the *Journal of Responsible Innovation* will publish a special section featuring 17 "Perspectives" pieces on responsible research and innovation in synthetic biology from workshop participants. Co-PI Brian guest edited the section; the pieces are derived from the two-page background papers participants prepared for the workshop and were peer-reviewed for publication.

(3) A detailed public website with videos from the workshop, interviews with participants, background papers, posters, notes from the graphic recorder, and short reflections/commentaries on the workshop has gone live and will continue to be elaborated.

The workshop PIs are also planning future events in Washington, DC, including a briefing for the National Academy of Sciences Forum on Synthetic Biology (co-chaired by co-PI Murray) and a presentation at the "New Tools for Science Policy" seminar offered by the Washington, DC office of ASU's Consortium for Science, Policy and Outcomes (co-directed by PI Guston). Through these events, we hope to generate substantive feedback on our conclusions, as well as relay the enthusiasm for and breadth of fascinating and critical new research questions and ideas to relevant agencies and potential collaborators.

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Appendix A: Sample Language for a Request for Proposals

As all innovations in science and technology, synthetic biology is co-produced along with innovations in society. Changes in social conditions, from practices in laboratories to legal and regulatory pronouncements to the nature of work and other social relations, occur reciprocally with changes in our ability to engineer biology. Society is more than a context for scientific and technical advance. Rather, it helps furnish everything from visions of what that advance looks like, to the material conditions that contribute the success or failure of those visions, to the values and criteria that adjudicate success and failure. Societal research – including empirical, theoretic and normative inquiries – can help assure the responsible innovation of synthetic biology by participating in informed discussions of how to define synthetic biology and its related fields, by tracking the history and ongoing state of its development, by creating processes through which different publics can express their hopes and concerns about it, by increasing the capacity of scientists and engineers to be appropriately responsive to such hopes and concerns, and by further developing general understandings of what, indeed, ideas of responsibility must mean in conjunction with increased skill in engineering life.

The overarching themes of co-production and responsible innovation can be explored through many different areas of societal inquiry, including research concerning: the creation and assessment of visions of synthetic biology futures and other anticipatory knowledge; the dynamics of research and innovation systems in synthetic biology, particularly with reference to creating a strong empirical foundation for understanding the global context; the developing public understanding of and attitudes toward synthetic biology, with comparative dimensions across geographies and specific technologies and applications; public engagement with synthetic biology through mechanisms ranging from informal science education to do-it-yourself (DIY) biology; questions of risk, sustainability and governance (both formal and informal) of synthetic biology, particularly in the contexts of the environmental health and safety questions that underlie biosecurity and biosafety, but also in the equity, fairness, future generations, and other values that underlie the emerging bioeconomy; and others.

Appendix B: Research Needs

On the last day of the workshop, participants identified a long list of immediate research needs. The list is not comprehensive, but rather gives a broad overview of critical research questions worth pursuing. We have broadly categorized them here:

Bioeconomy

Participants agreed that comparative and international research will be critical for making US policy in an era of the globalization of bioeconomies and of global biological systems. Some of the specific research questions they identified with respect to the bioeconomy include:

- What are the trade-offs in a bio-based economy? What would we stop producing in favor of synthetically bioengineered products?
- What are the trade-offs with respect to centralized or decentralized infrastructure for biomanufacturing – for both competitiveness and security?
- An interdisciplinary research and training initiative focused on bioeconomies, the reconfigurations (of relations among the social, biological, technological and economical) that they bring about, and the distributions of outcomes that flow from them.
- Notions of sustainability need to be "unpacked" and operationalized in the context of bioeconomy, and questions of how that can be done and who should be involved are of central importance. What is the role of syn bio in sustainability research?
- Relevant data and metrics are needed to account for and support decisions on investments
- While a sustainability focus is crucial, participants also identified a crucial need for a focus on health care in the bioeconomy.
- Need to better understand the connections between market and social goals. How do technology transfer policies, for example, help or hinder important social goals?

Responsible innovation

One of the larger sets of questions participants raised was "What are the desired goals and outcomes? What's the framework on which to hang a research agenda in a directed, not ad hoc way?"

- What are the conditions that would make responsible development in syn bio possible? What processes and institutions do we need?
- Innovations ecosystems affecting productivity and societal impacts from a 21st century perspective. This research would pay particular attention to key drivers and values.
- Leverage existing research operationalizing a sustainability framework to assess syn bio applications of the tradeoffs as one (or many) option(s) in a suite of other options for achieving societal objectives.
- Systematic consideration of alternative pathways for achieving stated goals of synthetic biology research. For a given "promise", what are other social/technical means of delivering on it?

Governance

Participants requested assistance from NSF to provide formal pathways for research to reach policymaking bodies. Strengthening (or creating, in some cases) a more efficient feedback loop between social scientists, policymakers and scientists is a critical need.

- How can we distinguish among science, science fiction, and hype? For which purposes must we? The time lag from idea to product is significant, and we face great uncertainty, yet we proceed to look for governance solutions. How do we make decisions in the face of uncertainty *and* a lack of transparency?
- What is the interface between the non-traditional developers and the traditional "hard" governance institutions?
- Coordinated and systematic mappings of international/transnational policies and governance structures as they emerge to produce comparative analyses of policies.
- Support for non-traditional "broker" roles, including support for policy interactions and communications between centers.

Cross-disciplinary and cross-sector collaboration

Participants noted a strong need for research on and development of methods for working across disciplinary and sector boundaries. They also noted a need for support for international work. Some suggestions were:

- Conduct social science research ("integrated" and not "integrated") about what professional researchers (in public and private sectors) that are funded by programs labeled as "syn bio", or in research centers uniquely devoted to 'engineering biology' are actually doing, and how this may contribute, or not, to broader aspirations of, for example, sustainability. This work across sectors aims to uncover (hidden) definitions of what 'good health, 'sustainability' or 'food security' look like.
- Focus on connections across topics, research to mitigate uncertainty on connections.
- Build societal research into specific problem areas. Create particular test beds and scale up from focused problem to wider application within that problem area.

Ethics, Public Values

Participants identified a strong need to understand who or what were the drivers in debates about norms and values in synthetic biology.

- Research to identify and assess success in education on norms across traditional and non-traditional practitioners in syn bio.
- Need to map the cultural diversity of the syn bio community writ large to understand competing worldviews and relation to empirical claims, theories of change, etc. This research question proposes taking a cultural thermometer to syn bio culture.

Informal Science Education and Public Engagement

Participants were eager to bring social scientists, engineers and practitioners together in more substantive ways, to better track the outputs and impacts of ISE.

- How can we measure the impact of investments in informal science education? This includes investments in museums, community labs, and academic efforts.
- How do we include the public in meaningful ways in the fast-paced world of scientific and technological advancements?