Public Understanding of Synthetic Biology

ELEONORE PAUWELS

The objective of this article is not to draw exhaustive conclusions about public perceptions of synthetic biology but to provide readers with an integrated review of the findings from 4 years of quantitative and qualitative research conducted on this subject in the United States. US public perceptions toward synthetic biology are ambivalent. Members of the public show enthusiasm for synthetic biology applications when those applications are developed to address societal, medical, and sustainability needs, whereas engineering biology is seen as a potential concern if this research is done without investigations of its potential risks and long-term implications. Members of the public also support funding for research that leads to applications that actually meet social and sustainability goals. When it comes to oversight, their priorities are to promote transparency and accountability and to ensure a form of tailored governance in which diverse knowledge sources help address the uncertainty surrounding new technologies.

Keywords: synthetic biology, public perceptions, framing, risk–benefit trade-off, application

The public perceptions of different sectors within the life sciences have received extensive attention in the last 30 years (box 1). What are some of the lessons to draw from the public-perception studies of biotechnology? Public opinion surveys have indicated that people's attitudes vary toward biotechnology, which affects consumer acceptance or rejection of the technology. An analysis of the survey results shows that public acceptance of biotechnology is influenced by a number of interrelating factors. The major influences on acceptance seem to be the state of knowledge and awareness of the benefits of the biotechnology; confidence and trust in the producers of the biotechnology; and the notions of risk, uncertainty, and complexity (e.g., Priest 2000, Fischoff and Fischoff 2001, Onyango et al. 2002, Bruhn 2007, McHughen 2007, Pauwels 2009).

According to some researchers, most lay people lack the knowledge to formulate a relevant opinion on biotechnology (e.g., McHughen 2007). However, decades of research in science and technology studies (STS) have contradicted the official science and policy reactions to public distrust—namely, that public backlash is due solely to public ignorance or to a knowledge deficit concerning science. On the contrary, researchers in STS argue that members of the public display a set of nuanced and situated grasps of science and technology, depending on whether there is a perceived usefulness of that knowledge for those individuals (e.g., Hill and Michael 1998, Felt et al. 2007). This notion of *perceived usefulness* illustrates that what matters most is the perceived direct benefits that biotechnological applications provide to specific groups within society. Moreover, STS researchers have also demonstrated how these understandings are anchored in deep cultural narratives that have nurtured, for decades, our conceptions and assessments of technological progress in Western societies (see, e.g., Kearnes et al. 2009, Davies and Macnaghten 2010, Macnaghten 2010, Nordmann and Macnaghten 2010).

Another significant parameter is trust. Whether the public trusts new technologies often depends on whether the public trusts the developers of those technologies or those responsible for ensuring public safety. Public expectations, if they are articulated and widely disseminated early in the development of a new technology, constitute a powerful form of social and market oversight. When industry is trying to introduce a new technology, public trust has large strategic implications as the market for that technology develops. A key variable for consumers is whether companies handle this new technology in a socially and environmentally responsible manner (Rejeski and Pauwels 2012).

Finally, an inherent difficulty in studying public perceptions of emerging technologies comes from the translation to a public audience of the uncertainty and complexity surrounding the development of these technologies. Even with limited expertise, members of the public are prone to focus on what can be considered *risk*, *uncertainty*, and *complexity*. In the "Synthetic biology implications in public communication" section, I will elaborate on this significant challenge

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in public communication and the ongoing controversies around how to interpret and use the data produced by large-scale public surveys, as well as how it should inform the governance of emerging technologies (see Hill and Michael 1998, Grove-White et al. 2000, Kearnes et al. 2006, Lezaun and Soneryd 2007, Felt et al. 2007, TNS–BMRB 2011).

Some STS critiques

Over the past years, many ways of organizing public-perception studies on issues linked to science and technology have been examined by STS researchers (e.g., Davison et al. 1997, Hill and Michael 1998, Grove-White et al. 2000, Kearnes et al. 2006, Lezaun and Soneryd 2007, Felt et al. 2007). They have stressed the impact of these concrete experiments concerning who is invited to the table, what issues can be addressed, what knowledge is considered relevant, and what importance public recommendations and questions might be given in the ongoing governance of science and innovation.

The question of the mobility of knowledge and opinions is an important issue for STS researchers. What is the relevance for the future of a momentary picture of how people perceive a technology in the present? Public-perception exercises may have a purely instrumental objective—to produce utility for government by incorporating public opinion into governance—but they can often expose a set of unknown, ignored, or undermined issues, visions, and perspectives. STS researchers suggest that rather than a static picture of the general public, studies about public understanding should focus on how the public produces new articulations of the technology under deliberation and what dynamics of knowledge they reveal.

In a nutshell, according to STS, it is imperative not simply to call for interrogating the public in technoscientific processes but also to reflect on issues such as the ways in which perceptions studies are designed and performed, the motivations behind them, the actors who are given a voice, when those actors are supposed to intervene, and so on.

Synthetic biology for the uninitiated

As is often said by synthetic biology proponents, synthetic biology is the engineering of biology (see Endy 2005, Carlson 2010). In particular, advancements in DNA synthesis and sequencing have enabled the engineering of microorganisms from discrete chemical parts, even allowing scientists to design to specification microorganisms capable of performing novel functions. In 2006, for example, University of California, Berkeley, researcher Jay Keasling and his colleagues at Amyris Biotechnologies succeeded in programming a microbe to produce artemisinin, an ingredient in antimalarial drugs (Ro et al. 2006). In May 2010, J. Craig Venter and his research team achieved another milestone when they successfully built the first synthetic bacterial genome and used it to take over a cell (Gibson et al. 2010). Beyond promising a range of applications from bioenergy to biosensors, synthetic biology promises to have a transformative impact on the ways in which we engineer and manufacture biological matter. In brief, this new technology could transform specialized molecules into tiny, self-contained factories, creating the needed components for drugs and fuels at lower costs.

To date, there is no argument to deny that synthetic biology may offer an unprecedented opportunity to transform modern medicine, generate clean biofuels, and promote more sustainable infrastructures. However, when new technologies emerge, optimism and enthusiasm often trump humility, and suddenly, scientists, engineers, and entrepreneurs actually believe they can predict and control outcomes in complex physical and biological systems. Several voices from the academic sector have also warned that the technology may develop in an unsustainable way in regard to environmental and societal concerns. Rodemeyer (2009) pointed to specific cases in which research processes and infrastructures used to develop synthetic biology products of first, second, and third generations will need more refined risk assessment procedures than those on which the US federal agencies currently rely (see Rodemeyer 2009). In her testimony to the US Presidential Bioethics Commission (PCSBI 2010), Allison Snow systematically described how ecosystems might be affected by the environmental release—intentional or unintentional—of synthetic organisms (*http://bioethics.gov/cms/meeting-one-transcripts*).

Indeed, too often, the public and policy debates surrounding synthetic biology have been narrowly focused on a utilitarian calculation of its technological benefits versus its potential regulatory risks. Although the technical aspects of synthetic biology policy are immensely important, spanning controversies on ownership, sociotechnical implications, and biosecurity and biosafety concerns, fundamental questions about what applications of synthetic biology would advance societal goals and be considered sustainable are ignored, and the discussion is therefore limited to the preoccupations of a few technocratic elites. However, the next section of this article shows how important it is for Americans to fund research on technological pathways that contribute to societal needs.

Survey and focus group data

Synthetic biology is a field that promises advances in energy, health care, and other potential areas, such as spatial and military research. How much do Americans know about it? Do members of the public think that the potential benefits of this emerging technology will outweigh the potential risks? What do they consider *socially useful* applications? What do they see as priorities in the governance of such an emerging technology? And how much confidence do they have in federal agencies' ability to adequately regulate synthetic biology?

These questions were part of a series of three representative national telephone surveys, each of over 1000 US adults, conducted by Hart Research Associates (2008, 2009, 2010; see box 2) on behalf of the Science and Technology Innovation Program at the Woodrow Wilson International Center for Scholars. Even though these data are relatively extensive, survey data of this kind seldom provide a sufficiently detailed picture from which to adequately infer national trends. Survey research should be complemented by qualitative contextual studies intended to explore popular understandings and images of new technology. To this end, I also use 16 hours of focus group data collected in Baltimore, Maryland, in August 2008, 2009, 2010, and 2011 among (18–65-year-old) adults to contextualize the abovementioned quantitative surveys and to more deeply explore both uninformed and informed perceptions of synthetic biology in the United States (see box 2).

My objective in this article is not to draw exhaustive conclusions about the public perceptions of synthetic biology but, rather, to provide readers with an integrated review of findings from 4 years of quantitative and qualitative research conducted on this subject. However, whereas three reports (Hart Research Associates 2008, 2009, 2010) have already been published on the previously mentioned quantitative data, few documents (see Pauwels 2009) have yet reported on the qualitative data. This is why, in the present article, I give qualitative insight into what words, images, and cognitive shortcuts to previous technologies members of the public use to frame synthetic biology; what applications they potentially welcome; what kind of perceived risks would prove acceptable to them; and what actors and parameters would increase their trust in society's ability to manage synthetic biology's technological risks.

Box 2. Details of the Hart Research Associates surveys and the focus groups.

The three national surveys by Hart Research Associates (2008, 2009, 2010) were focused on the question of US public awareness of synthetic biology, perceptions of its potential risk–benefit trade-offs, and possible options for oversight. The surveys also included an open-ended question on the words and images used by members of the public to describe synthetic biology. This constitutes a set of representative data that can be used to gauge general appraisal of synthetic biology risks and benefits in the United States. However, the 16 hours of focus groups added insight on what specific applications may be welcomed by members of the public and which types of perceived risks may lead to public uneasiness. The focus groups also provided data about the framing of synthetic biology that would be least accessible without the kind of interaction found in a group setting: Listening to others' verbalized experiences stimulates ideas and experiences in the participants. All the materials used in the telephone survey and in the focus groups have been developed and checked in collaboration with academics recognized in the field of synthetic biology.

Hart Research Associates conducted three nationwide phone surveys. The first, conducted in August 2008 among 1003 adult respondents, was about the respondents' awareness of and attitudes toward synthetic biology. The September 2009 survey, conducted among 1001 adult respondents, was on the respondents' attitudes toward the entities involved in the oversight of new scientific and technological advances and on the respondents' awareness of and attitudes toward synthetic biology and its applications to the creation of synthetic biofuels. The third survey, conducted in August 2010 among 1000 adult respondents, was also on the respondents' attitudes toward the entities involved in the oversight of new scientific and technological advances and the respondents' awareness of and attitudes toward synthetic biology. The survey also included a discussion of two potential applications of the science. The 95% confidence interval for all three surveys was 3.1. Indeed, every respondent was asked every question, so there were no dropped base questions for the totals line.

The Science and Technology Innovation Program at the Woodrow Wilson International Center for Scholars and Hart Research Associates also conducted a series of eight sessions of focus groups (in total, 16 hours) in Baltimore, Maryland, in August 2008, 2009, 2010, and 2011, with 18–65-year-old adult participants, in order to explore both uninformed and informed impressions of synthetic biology. The results of these focus groups are limited and should not be considered to represent anything more than a sample of public opinion toward synthetic biology and should not be used to draw definitive conclusions. Although the views of the focus group participants were prone to be influenced by group dynamics, these focus groups were moderated by professionals from Hart Research Associates. Detailed information on the focus groups (i.e., the experimental conditions and participants' backgrounds) is provided in the supplemental materials, available online at *http://dx.doi.org/10.1525/bio.2013.63.2.4*.

Public awareness of synthetic biology. Most Americans remain unfamiliar with synthetic biology. However, despite being relatively low, public awareness of synthetic biology in the United States has nearly tripled over the past 3 years, with 26% of the survey respondents in 2010 saying that they were aware of the topic. This is up from 22% in 2009 and nearly three times the percentage (9%) of those who said that they had heard about synthetic biology in 2008 (figure 1). Just 43% of the respondents said that they had heard nothing at all about it, down from 67% two years ago. When asked about the recent announcement by the J. Craig Venter Institute (Gibson et al. 2010) of its creation of a partly synthetic life-form on the basis of DNA produced in a laboratory, nearly one in four (24%) adults said that they recalled hearing about it. Fully 57% of those who reported the greatest awareness of synthetic biology said that they recalled hearing about this recent development.

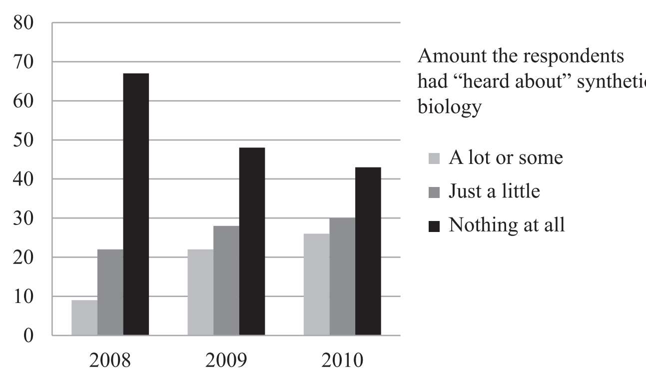

Figure 1. Public awareness of synthetic biology (Hart Research Associates 2008, 2009, 2010), represented by the percentage of responses at each of three levels of awareness.

Despite their limited awareness of synthetic biology, 7 in 10 respondents reported some sense or idea about what they think synthetic biology involves, and their top-of-mind perceptions were focused mainly on the concept that it is humanmade or artificial (30%). Fully 12% said that it has something to do with genetic engineering or with modifying or altering plants, crops, and cells. Smaller percentages of the respondents mentioned science or biology (6%); cloning (6%); machines, drugs, or advancements in medical research (5%); or synthetic materials and chemicals (5%). Nearly a third (29%) of the respondents had no sense of synthetic biology or did not offer a response.

The focus groups allowed us to explore in greater detail individuals' impressions of synthetic biology and the associations that they make with it. In general, the impressions of synthetic biology expressed in the focus groups mirrored the survey responses (box 3).

Perceptions of the risk–benefit trade-off of synthetic biology. When they were initially asked to characterize their feelings about

Box 3. Some brief definitions of *synthetic biology* given by the focus group participants.

"It sounds like a manmade replacement for existing biological organisms or products, like everything from—it almost seems—artificial flavoring up to artificial tissue for the body."

"Cloning and stem cells and harvesting organs for the future."

"What the term makes me think of is something humanmade to mimic nature. It's about molecular compounds and playing God."

"The term *synthetic biology* makes me think of genetic engineering and something lab grown."

"Growing human replacement parts comes to mind. I think of mice with human ears growing out of them and of artificial works."

"I think of constructing animals or plants in a lab setting with materials not typically associated with the process. Frankenstein comes to my mind."

"I think of taking a drug that comes from a plant and making it without having to use the plant anymore."

"I view it like sci-fi movies, where something is created in a laboratory, and it always seems great in the beginning, but down the line, something goes wrong because they didn't think about this particular situation or it turning [out] this way."

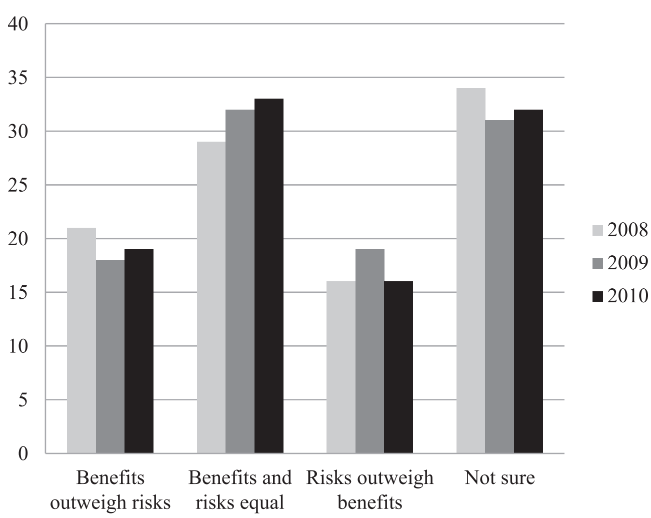

Figure 2. Respondents' initial impressions of the risks and benefits of synthetic biology (Hart Research Associates 2008, 2009, 2010), represented by the percentage of respondents who chose each response option.

the risk–benefit trade-off of synthetic biology without any information, 68% of the respondents expressed a point of view, whereas 32% said that they were not sure. Most of the respondents believed that the risks and benefits would be about equal (33%), whereas 19% thought that the benefits would outweigh the risks, and a comparable 16% thought that the risks would outweigh the benefits. As is shown in figure 2, the initial perceptions of the risk–benefit trade-off of synthetic biology were similar in 2008 and 2009.

After hearing a balanced description of synthetic biology, including some of its potential benefits and risks, 37% of the respondents said that they believed that the risks and benefits would be about equal (up four points from an initial 33%), whereas 33% believed that the risks would outweigh the benefits—twice the initial assessment (16%). The percentage of adults who believed that the benefits would outweigh the risks (26%) also increased (up seven points from 19%). Converging with the above-mentioned results of 2010, the Hart Research Associates (2008, 2009) surveys show that, after learning about synthetic biology and being informed of its potential risks and benefits, the greatest shift in participants' opinions was toward there being more perceived risks (figure 3). As an illustration of these quantitative findings, a comparison of the uninformed and informed perceptions of the focus group participants contradicts the familiarity argument, according to which support for emerging technologies is likely to increase as awareness of them develops (see Sparks et al. 1994, Bauer et al. 2000, Cobb and Macoubrie 2004). In fact, confronting the focus group participants with balanced information about synthetic biology did not simply lead to more or less support for the technology but to a more nuanced level of discussion that showed, for example, the participants' relative ambivalence toward the inherent uncertainty and complexity surrounding the technology. The qualitative approach adopted

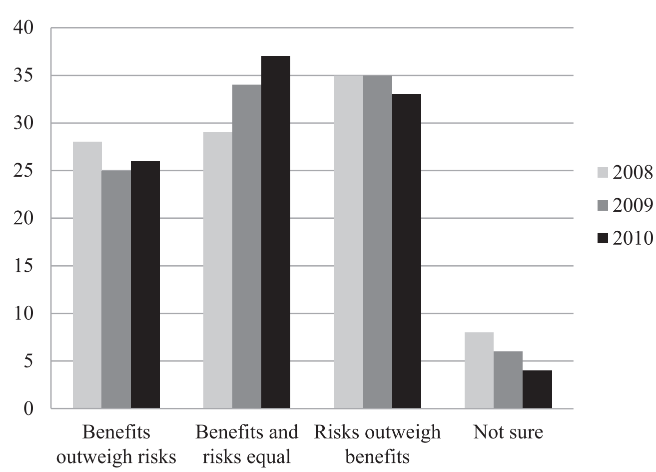

Figure 3. Respondents' informed impressions of the risks and benefits of synthetic biology (Hart Research Associates 2008, 2009, 2010), represented by the percentage of respondents who chose each response option.

here yields additional insights into how lay people frame synthetic biology and its applications.

Framing synthetic biology and its implications. The participants tended to describe synthetic biology by drawing parallels with other biotechnology or biomedical fields. These analogs (i.e., "cloning, cloning procedures"; "genetic engineering"; "stem cell research"; "recombinant DNA research"; "regenerative medicine") show how the participants framed the concept of synthetic biology and what other technologies they associated with it, and it is why these analogs or references might be crucial to anticipating the lines along which future public debate about synthetic biology may evolve. Before being given a definition of synthetic biology and being informed of potential applications of the technology, the participants tended to view the field in relation to previous technologies, such as cloning, stem cell research, and genetic engineering. In the focus group exercises, when she was attempting to describe synthetic biology, one of the participants mentioned the activity of "cloning, trying to change naturally occurring living objects into manmade objects." While professing his lack of knowledge, another participant was capable of making more accurate references to existing technologies: "I am not really sure. Genetic engineering and cloning come to my mind. Maybe something to do with recombining DNA and technology." When the focus groups' moderator asked the participants to elaborate on these initial analogs to provide a brief definition of synthetic biology, similar references came up in the discussion, such as "continuing to utilize cloning procedures to 'grow' human organs from stem cells, to perhaps genetically engineering whole organisms."

References made to existing technologies are a window into the participants' initial perceptions of synthetic biology. These analogs provide a way of looking ahead by looking back. They contribute to the framing of the technology by the participants and reveal the cognitive shortcuts that they will likely use when learning more about synthetic biology. In the next section, I compare the preliminary analogies used by the participants with their comments and reactions after they were given information about synthetic biology. This comparison allows us to evaluate the influence of new information on the attitudes and perceptions of the participants toward synthetic biology and to assess the extent to which they will rely on their previously conceived cognitive references or shortcuts to process the information.

Ambivalence toward engineering life. In reaction to the reading materials on synthetic biology, the participants expressed relative ambivalence about the engineering nature of synthetic biology and the goal of redesigning life-forms. One of the male participants expressed this ambivalence in the following terms: "The prospect excites me; I think it has to do with attempting to create something from nothing or from very little. I feel [that] it could be beneficial to us. It could also be dangerous if we do not research it enough to find out any long-term effects." Other comments revealed discomfort with the term *synthetic biology* and fears about the technology being used in a negative way: "This term [*synthetic biology*] makes me feel scared. This could lead to huge scientific advances, but it can also lead to countries or people using it for their own 'evil agendas.' It reminds me of *Jurassic Park*." Another area of uneasiness for the participants was the idea of synthetic biology being used in "creating life." One of the participants expressed her apprehension by highlighting her uncertainties about researchers' ability to control or manage such experiments: "I feel concerned because, not being perfect, we believe we know what is best in creating life. As in science-fiction movies, when we do—in time—it goes in a direction we didn't think about… I believe [that] when life is created, it is meant to be created that way for a purpose we may not even know right now."

The discussion about the possibility of creating new genetic code and its subsequent instrumental use seemed to provoke a general feeling of discomfort among the participants: "This 'synthetic biology' involves [the] engineering of genetic codes, requisites to genetic engineering. I mean, it seems like, to me, that with this, you don't even need a base DNA. You just create it…. I don't like it"; "Making a brand new code, I think it is dangerous." Although he felt positive about the field's possible applications, one of the participants expressed his moderate concern about the limits of synthetic biology: "It may be highly profitable. Maybe it could be used to extend life. It seems exciting but makes me somewhat uncomfortable. Where are the limits?" This intuitive feeling of discomfort led one of the participants to question the limits of human agency with the well-known "playing God" argument: "It sounds like we are playing God. Who are we as humans to think [that] we can design or redesign life? It might be nice to be able to do so, but is it right? It seems [that] there are many ethical and moral issues. Perhaps we are getting too arrogant."

Lack of understanding and *what if* scenarios. Concerns about the unintended consequences of synthetic biology appeared across the groups and even among people with generally positive views of synthetic biology. The uncertainty associated with something new and unknowable led some of the respondents to wonder what could happen if something went wrong and what might happen in the future (box 4).

Even the best precautions and regulation cannot make up for unforeseeable consequences of using a new technology, especially when it comes to applications that deal with larger spheres of life, such as the manipulation of malaria-bearing mosquitoes. When given a scenario in which scientists engineer sterile mosquitoes to reduce the spread of dengue fever, some participants expressed concerns that altering nature could have negative consequences downstream. One participant referred to the "butterfly effect," in which one small change in the environment can have worldwide ramifications. As one participant put it, "I feel

Box 4. Quotes from the focus group participants about *what if* scenarios.

"I think you open sort of a Pandora's box and there's opportunity for things to go wrong or an experiment to get out of hand or you mutate a living animal's DNA. And I just—you don't know what you are going to get, I guess, in the final product."

"We can think about what sort of life-form we would like to make and design it like a car; we could alter nature and guide human evolution; we can put it in a microbe, and two weeks later, out comes your product? Those are all very, very scary thoughts that somebody has that power."

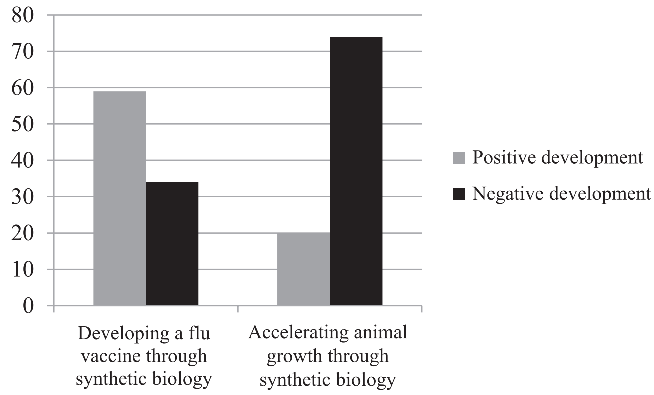

Figure 4. Public perceptions of specific synthetic biology applications (Hart Research Associates 2008, 2009, 2010), represented by the percentage of respondents who saw the two given scenarios as positive or negative.

like everything is kind of there for a reason…. Spiders are icky, but they kill mosquitoes. They are needed."

The apprehensions expressed by the focus group participants around wild-card scenarios and the uncertainties inherent in tinkering with life were well mirrored in the survey responses about security and moral concerns. Indeed, the respondents expressed equal levels of concern about synthetic biology's use to create harmful biological weapons (27%), about the morality of creating artificial life (25%), and about negative health effects for humans (23%). A lesser 13% said that the possibility that it could damage the environment was their biggest concern.

Potential applications matter. Another relevant element in the framing process of emerging technologies—and this appears to be the case in both the surveys and the focus groups—is that applications matter. The participants made different value judgments about synthetic biology depending on its specific applications. Some applications generated greater optimism among most of the respondents, whereas others generated a great deal of concern. Synthetic biology, of course, spans a very wide range of potential applications, from health to energy and the environment, and the examples that we provided to the respondents reflected this diversity. As might be expected, the type of synthetic biology application influences the form of the discussion, anticipated reservations, and conclusions. For example, in Hart Research Associates (2010), respondents were presented with two potential applications for synthetic biology: using it to dramatically expedite the creation of an influenza vaccine and using it to accelerate growth in animals. The respondents reacted in very different ways to these applications. A majority (59%) of their responses were positive about the vaccine application. In contrast, nearly three in four (74%) of the participants viewed the use of synthetic biology to accelerate the growth of cows and pigs as a negative development that causes them concern (figure 4).

Applications to the environment are seen as particularly promising. Despite concern about the risks of synthetic biology, by 52% to 38%, the survey respondents thought that we should encourage the development of synthetic biofuels rather than discourage it. These findings were confirmed by the focus groups. One focus group participant expressed her enthusiasm by saying, "Sounds great; good deal; biofuels, I love that." Comments from other participants echoed this enthusiasm: "I really like the idea of generating, constructing a bacteria to generate hydrogen." Within the energy issue, the participants also expressed their concerns about protecting the environment: "[Bacteria that generate biofuels] would be fantastic, between that and—you know, I believe we have already come up with some bacteria that will eat away stuff in landfills and pollutants and so forth for environmental cleanup. Between those two, I think it would be really helpful to the world."

Interestingly, the applications that were viewed as more contained elicited less concern, because the participants wanted a secure environment in which the science can be applied to specific causes safely and effectively. For example, the participants were much more amenable to the idea of using synthetic biology to create an antimalarial drug in a laboratory than to that of combating the mosquito-borne dengue virus by releasing altered mosquitoes into the environment. The importance of containment as it was defined by the participants' responses leads us to examine another governance issue: oversight.

Building trust: Oversight and transparency. The respondents expressed a strong appetite for more information about synthetic biology. There was a broad consensus that "more should be done to inform the American public" about synthetic biology research. In Hart Research Associates (2009), 9 in 10 of the respondents agreed with this statement, including 73% who strongly agreed. The participants also approached synthetic biology with a sense of tentative support and guarded optimism. Although most did not want to stand in the way of this research, they also did not want to let it proceed without government oversight. In Hart Research Associates (2010), the large majority of the respondents

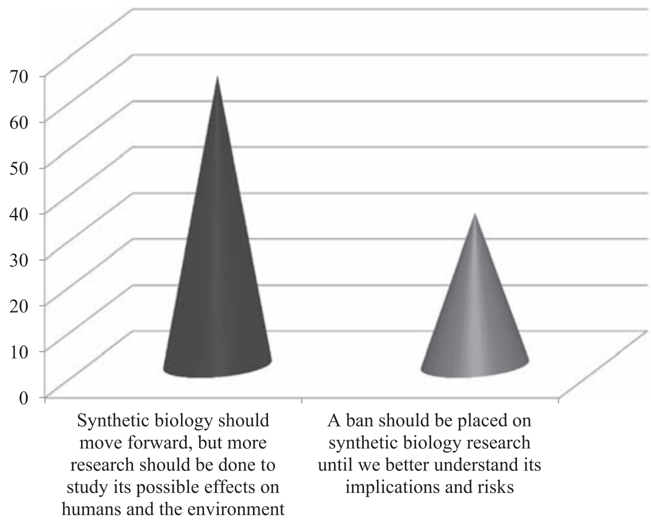

Figure 5. Public support for synthetic biology research (Hart Research Associates 2010), represented by the percentage of respondents who chose each of the response options.

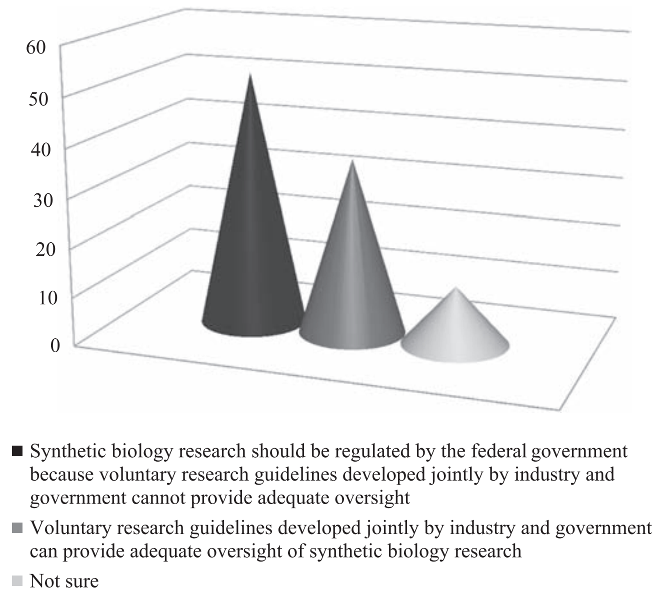

Figure 6. Public opinion on the oversight of synthetic biology research (Hart Research Associates 2010), represented by the percentage of respondents who chose each of the response options.

believed that rather than synthetic biology being banned, research and development should move forward with a focus on uncovering possible effects on humans and the environment (63%). Only one in three (33%) respondents supported a ban on synthetic biology research until its implications and risks could be better understood (figure 5). The majority of the participants also felt that when it comes to synthetic biology research, voluntary guidelines do not provide adequate oversight. More than half (52%) of them thought that synthetic biology should be regulated by the federal government, whereas 36% thought that voluntary guidelines developed jointly by industry and government could provide adequate oversight (figure 6).

Once again, the focus group data contributed nuanced insights into what the participants saw as the best approaches to managing the risks associated with synthetic biology and what they saw as possible ways of increasing public trust. Here is a comment from a participant:

> I feel [that federal regulation] is the best approach, because I don't agree with banning [synthetic biology]. Technology should advance, and in order to advance… there's risks with it. Anything that we have today comes at a risk, but… I think of the four [options provided], the federal government would be the best. And I guess it would be more in the spotlight than just some private company and its investors.

He continued his explanation by referring to the broad principle of political accountability: "At least…, technically, we choose the government, so if they screw up, we can vote them out of office. And with all of the people on television discussing everything, it's probably harder for the government to whitewash an issue as opposed to a private company."

After having discussed with the participants the best approach to managing the risks associated with synthetic biology, the focus groups' moderator asked questions concerning the ways in which the federal government could work to increase public trust. The concern over the competence of government agencies to regulate synthetic biology brought forward many suggestions that scientists or research institutions needed to participate in oversight along with the regulatory agencies. One of the participants expressed her reason for involving scientists in the regulatory process: "I think [that] they should be part of the team, because they bring so much knowledge and understanding." In general, keeping regulation above the political fray by involving scientific experts was important for the participants.

The participants also spoke about enacting a hybrid approach—a kind of private–public partnership that would lead to a better system of checks and balances. As was mentioned by one of the participants, "I guess I would feel more comfortable if there was a system of checks and balances… like the government. Not that that's my first choice, but it seems like it's the only independent option for checking—a system of checks and balances." Another participant went even further: "So, we're going to have to set up, I believe, a total new framework of so-called 'commissions and oversights.'" Another participant mentioned the idea of having a third-party overseeing the industry activity: "Regulation [should include] a third party, an unrelated organization, [to] watch over the industry. And that's why we have them, because they have no interest. They are not connected. They are not getting any profit. They are there to certify or check, independent of those who are making the money." This idea of a system of checks and balances seemed to be the best way of securing accountability and providing the public with information about the research applications: "The knowledge that should something go wrong, there will be repercussions—the checks and balances thing—just so long as if anything goes wrong, someone will be held accountable. They won't be just buying their way out of it. There will be a nice little way to know."

In a nutshell, what these quantitative and qualitative data tell us is that public perceptions toward synthetic biology are ambivalent: If there is no trace of candid optimism, there is also no unilateral technology rejection. The survey respondents and focus group participants showed enthusiasm for synthetic biology applications when those applications were developed to address societal, medical, and sustainability needs. Tinkering with the DNA of existing or newly designed organisms was seen as a potential concern if this research were to be done without sufficiently funded investigations of its potential risks and long-term implications for humans and the environment. In general, the participants also remained quite skeptical about futuristic technological visions based on hype or technoscientific promises; they supported an allocation of funding for research that would lead to applications that actually meet social and sustainability goals. When it comes to oversight, their priorities were to promote transparency and accountability and to ensure a form of tailored governance in which expertise is accompanied by independent checks and balances and in which diverse knowledge sources might help deal with the uncertainty surrounding a new technology.

Box 5. Visions of synthetic biology in one example from the media.

"'What if we could liberate ourselves from the tyranny of evolution by being able to design our own offspring?' Drew Endy asked, the first time we [met] in his office at MIT, where, until the summer of 2008, he was assistant professor of biological engineering.… Endy said, 'If you could complement evolution with a secondary path, decode a genome, take it off-line to the level of information.'"

"Keasling and others in the field, who have formed bicoastal clusters in the Bay area and in Cambridge, Massachusetts, see cells as hardware and genetic code as the software required to make them run. Synthetic biologists are convinced that with enough knowledge, they will be able to write programs to control those genetic components, programs that would let them not only alter nature but guide evolution as well" (Specter 2009).

Synthetic biology implications in public communication

In the scientific and public spheres, synthetic biology fits into a regime of innovation based on technoscientific promises (see Felt et al. 2007) and is therefore epitomized through metaphors and narratives that involve the articulation of a vision. This articulation often takes the form of hype. Vision and hype are both types of discourse that look toward the future. The vision of synthetic biologists is a future in which humans engage in the large-scale design and creation of new life-forms that are exquisitely tailored for human purposes. The genetic engineering of organisms and the extensive design and manufacture of living things from virtual genetic sequences blurs the line between machine and organism, life and nonlife, and the natural and the artificial and therefore transforms the relationship between humankind and nature in ways that are exciting to some people but troubling for others (see Bedau 2009). The visions of our biotechnical futures as they are presented in the media, either by scientists or by journalists, are usually quite powerful (box 5).

The second quotation in box 5 was actually presented to the focus group participants and provoked relative discomfort. Reading this statement, the focus group participants were actually prone to think that in the near future, there might be a need to explore the readiness of the engineering profession to address the ethical and social issues associated with our biotechnical futures. The possibility of error—human or otherwise—is why history is important when we think about future technologies. How well have we managed the introduction of other technologies? Have we, as a society, learned anything?

This kind of discomfort expressed by the participants goes well beyond the "playing God" argument, which is overly used as a way to epitomize and sometimes caricaturize public concerns over new technologies. What is evident in the participants' discomfort is a resistance to the dominant technoscientific narratives of biological control, which are encapsulated by synthetic biology. What they usually expressed was a form of humility toward what we think we know and control despite the recurrent effects of systemic uncertainty and complexity. This notion of systemic uncertainty and complexity was well described by Wynne (2009) under the term *epistemic other*, which he defined as "difference manifesting itself as an unknown set of realities, acting themselves as unknowns and beyond our control (but not beyond our responsibility), into a world we thought we controlled" (p. 13).

If synthetic biology involves many uncertainties, it is also because this science is very much a hybrid—a complex interaction of scientific domains—that is still under construction. And although there is a lot of interesting research being done in the laboratories, the field is presented outside of the lab, in public media, in a somewhat simplified, hyped, or reductionist manner (box 1). For example, researchers in synthetic biology or science journalists frequently use metaphors when communicating with audiences outside the field. These metaphors tend to have an explicative or illustrative role in describing the science. However, metaphors are also used when the governance or the implications of synthetic biology are discussed. In most cases, the metaphors provided by synthetic biology insiders are used to make challenging concepts more understandable and relatable. Sometimes, we even observe a form of "debiologization." By leaving out important biological details, what is communicated is a picture very different from reality about researchers' ability to engineer biological systems. By using metaphors such as the "software of life," an analogy is drawn between biological and computational systems that allows synthetic biology to borrow important definitions for concepts such as *feedback loops*, *information*, *robustness*, and *noise* from its engineering counterpart. Interestingly, these concepts are not static. They are refined through scientific practices, and their meanings differ depending on the researcher or context involved. For example, for some researchers, *noise* relates to a complexity that should be avoided; for others, it constitutes a source of uncertainty that can be negative or positive and that can lead to unexpected discoveries. This plasticity of metaphors and related concepts should be exploited.

The exploration of the role of mental representations and language in the construction of scientific reality has important implications for policy and public communication. Comparing living organisms to computers implies that we have an understanding of and control over the function, reliability, and purpose of living organisms. This is a misleading perception that contradicts what experts in biological complexity have attempted to express—the notorious complexity and context dependency of biological systems and the delicate balance that needs to be struck for these systems to be viable. On this subject, the testimony of the biologist Bonnie Bassler (8 July 2010) in front of the US Presidential Bioethics Commission is eloquent:

> Synthetic biology is a young field, and it faces hurdles. The first one concerns reliable function. Even when scientists believe they know the components in a particular pathway, when we put them together using synthetic biology, they often fail to mimic the natural performance of the device. Natural systems do not fail when the conditions change; rather, they adjust to new environments. We do not understand why synthetic circuits are flimsy and natural circuits are sturdy.
>
> *http://bioethics.gov/cms/meeting-one-transcripts*

Interestingly, this comment shows the extent to which the metaphors contradict what scientists (e.g., biologists) know about biological systems and how they usually perceive them (e.g., as complex and unstable). If researchers in synthetic biology are aware of the relative weaknesses of the analogy around the "software of life," the narratives produced in its wake might affect not only public perceptions and trust but might also have broader ramifications that would influence the debates on safety assessment and ownership. As was eloquently said by Philip Ball in *Nature*, these are not anodyne issues that can be forgotten in the excitement of scientific discovery:

> Books of life, junk DNA, DNA barcodes: All these images can and have distorted the picture, not least because scientists themselves forget that they are metaphors. And when the science moves on—when we discover that the genome is nothing like a book or a blueprint—the metaphors tend, nonetheless, to stick. The more vivid the image [is], the more dangerously seductive and resistant to change it is.
>
> Ball 2011

Finally, the most important conclusion of this article is the need for additional investigation of different factors that will shape public perceptions about synthetic biology, its potential benefits, and its potential risks. Future analyses of the framing process of emerging technologies will require a range of interdisciplinary methods that are perceptive of cultural values and the context of applications. This would help scientists continue listening to public concerns about research—and to respond appropriately—so they can maintain the public trust, which will lead to a better coevolution of science and society.

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Eleonore Pauwels (eleonore.pauwels@wilsoncenter.org) is a research scholar with the Synthetic Biology Project within the Science and Technology Innovation Program at the Woodrow Wilson International Center for Scholars, in Washington, DC.