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# Designing Participatory Technology Assessments: A Reflexive Method for Advancing the Public Role in Science Policy Decision-making

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ABSTRACT

Decades of social science scholarship have documented and explored the interconnected nature of science, technology, and society. Multiple theoretical frameworks suggest the potential to direct this process of mutual shaping toward desired outcomes and away from undesired ones through broader inclusion of new voices and visions. In 2010, a group of researchers, educators, and policy practitioners established the Expert and Citizen Assessment of Science and Technology (ECAST) network to operationalize these frameworks. Over the course of a decade, ECAST developed an innovative and reflexive participatory technology assessment (pTA) method to support democratic science policy decision-making in different technical, social, and political contexts. The method's reflexive nature gave rise to continuous innovations and iterative improvements. The current ECAST pTA method includes three participatory phases: 1) Problem Framing; 2) ECAST Citizen Deliberation; and 3) Results and Integration. Proving adaptable and replicable, the method has generated outputs for decision-making on a variety of science and technology issues and at governance scales ranging from the local to the national and international. ECAST's distributed network model has also promoted independence, continuity, and sustainability through changing sociopolitical contexts. In this paper, we detail the current state of the ECAST pTA method; share mini case studies to illustrate circumstances that prompted new method innovations; and offer a vision for further developing and integrating pTA into democratic science policy decision-making.

## 1. Introduction

Decades of social science scholarship have documented and explored the interconnected nature of science, technology, and society—with science and technology shaping, and concurrently being shaped by, society (see Felt et al., 2017). These insights would seem to hold the possibility for a conscious social steering of this process of mutual shaping toward desired outcomes and away from undesired ones. Such an ambition lay behind early formulations of the idea of technology assessment (TA) (Arnstein, 1977), and its embodiment in government TA offices in the U.S. and Europe (Herdman and Jensen, 1997; Vig, 1992). But another pathway focused not on government policy apparatus but rather on expanding the range and diversity of perspectives involved in science and technology policy decision-making. Proposed frameworks such as Extended Peer Review, Constructive Technology Assessment, Responsible Innovation, Anticipatory Governance, and Real-Time Technology Assessment offered guidance on the governance of emerging science and innovations, as well as ways to utilize social values to direct the paths of innovation toward positive societal outcomes (Barben et al., 2008; Funtowicz and Strand, 2007; Guston and Sarewitz, 2002; Schot and Rip, 1997; Stilgoe et al., 2013). These frameworks each proposed broader inclusion of new voices and visions to contribute to science and innovation and explore alternative futures.

Participatory technology assessment (pTA) encompasses a class of methods for integrating new kinds of social actors into science policy discussions (Joss and Bellucci, 2002). These methods first gained traction as a decision support tool in Europe when the Danish Board of Technology experimented with a method of pTA called consensus conferences beginning in the late 1980s. Similar efforts emerged in the Netherlands and the United Kingdom in the early 1990s (Joss and Bellucci, 2002; Sclove, 1995). Consensus conferences, citizens' juries, and citizens' assemblies all serve to integrate a broader variety of

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perspectives into deliberations about science and technology than standard governance mechanisms (Rowe and Frewer, 2005).

Amidst new European initiatives to expand democratic input into science and technology assessment (Joss and Durant, 1995) and a TA capacity vacuum left by the demise of the U.S. Congressional Office of Technology Assessment (OTA) in 1995, a group of researchers, educators, and policy practitioners from the Arizona State University Consortium for Science, Policy and Outcomes; the Museum of Science, Boston; SciStarter (a nonprofit group that promotes citizen science); the Loka Institute (a nonprofit group that seeks to strengthen democratic input into science and technology); and the Science, Technology and Innovation Program at the Woodrow Wilson International Center for Scholars, put forward a concept paper in 2010 to develop a new institutional capacity in the U.S. that could integrate public engagement into future TA activities (Sclove, 2010). Though the concept paper argued that this new capability should reside in Congress as part of a reinstated OTA, it also recognized some of the challenges with a formal institutional structure, especially that large, bureaucratic institutions often struggle to innovate in the absence of nationally perceived crises and bipartisan policy windows (Delborne et al., 2013).

As an alternative to a formal government structure, the concept paper suggested the creation of the Expert and Citizen Assessment of Science and Technology (ECAST) network, a distributed network bringing together universities, science centers, and nonpartisan policy think tanks to conduct pTAs on complex, contested, and emergent science, technology, and society issues. The network had five objectives (Sclove, 2010):

1. **Combine participation and expertise**: Incorporate effective citizen participation methods to complement expert analysis;
2. **Adopt a 21st-century structure**: Develop a partially decentralized, agile and collaborative organizational structure, seeking TA effectiveness, low cost and timeliness;
3. **Continually innovate concepts and practices**: Encourage, evaluate and, as warranted, adopt new TA concepts and methods;
4. **Be nonpartisan in structure and governance:** Establish the ethos and institutional structures needed to ensure that any new TA institution is strictly nonpartisan. When there are strongly divergent normative perspectives on a particular topic, individual TA projects can benefit from a balanced, overtly value-pluralistic or multipartisan approach; and
5. **Be committed to transparent process and public results**.

After a demonstration project providing citizen input to the United Nations Convention on Biological Diversity in collaboration with the Danish Board of Technology (Worthington et al., 2012), ECAST piloted its first independent pTA project with the National Aeronautics and Space Administration (NASA) on its Asteroid Initiative (Tomblin et al., 2015). This paved the way for pTA projects with the Department of Energy on nuclear waste disposal and with the National Oceanic and Atmospheric Administration on community resilience.

ECAST's portfolio now includes projects on climate intervention research, automated vehicle futures, and gene editing, supported by more than three million dollars of public and philanthropic funding over the past five years. Strong funding support in recent years highlights a growing focus on public engagement. In the past decade, public engagement in the early phases of science and technology policymaking advanced from being an afterthought to a principal recommendation by major scientific advisory bodies (see, for example, NASEM, 2008; NWTRB, 2016; PCSBI, 2016). Outside the scientific community, leaders at large philanthropic organizations acknowledged: "We need to engage in and support the messy, complex work of civic discourse and negotiation" (Christopherson et al., 2018). Private sector actors have also emphasized the importance of engagement work. For example, the head General Motors' autonomous vehicle (AV) development company recently asserted, "This [AV development] is something we need to do with society, with the community, and not at society" (Kolodny and Schoolov, 2019). Through its projects and development of its pTA method, the ECAST network has helped to both meet, and further stimulate, this demand for public input.

### 1.1. *What we've done*

Over the past decade, we[1] have conducted 40 citizen deliberations in 18 different U.S. cities, engaging approximately 2100 participants (Table 1). An additional 35 deliberations scheduled for 2021–2022 will double the number of participants while adding at least 24 new locations. Our distributed network model and commitment to continuous learning and innovation have allowed for sufficient flexibility to develop a reflexive pTA method that can be replicated and scaled from the local and regional, to the national and global levels. Applied across a range of topics, the method has generated inputs for decision-makers, often in response to specific demand for such inputs, in the public, private, nongovernmental, and academic sectors.

In this paper, we describe how inclusion of a broad set of voices can facilitate democratic decision-making in the high-stakes, high-uncertainty context in which many critical science policy decisions occur. Just as society shapes science and innovation, social and political circumstances have influenced our work and pTA method. To illustrate these effects, we outline the current state of our pTA method and provide abbreviated case studies of some of our projects to highlight circumstances that catalyzed innovations to our method. Finally, we reflect on lessons from a decade of operationalizing pTA and offer a vision for further developing and integrating pTA into democratic science policy decision-making.

### 1.2. *Typology of terminology*

Many terms used in this paper carry different meanings in different societal and scholarly contexts. For clarity we offer our working definitions for these terms in table 2.

## 2. Background

Many scientific and technological issues with which policymakers grapple exist in what Funtowicz and Ravetz (Funtowicz and Ravetz, 1993a) termed the "post-normal age" wherein facts are uncertain, values are in dispute, stakes are high, and decisions are urgent. Beyond the confines of a controlled laboratory setting, complex sociotechnical issues are steeped in technical, methodological, and epistemological uncertainties which traditional scientific approaches cannot eliminate completely (Funtowicz and Ravetz, 1990). Persistent uncertainties

[1] The authors use first person perspective to broadly capture the contributions of multiple members of the ECAST network. Not all network members were involved in every project but they remained an integral part of ECAST's intellectual and institutional structure.

[2] These deliberations were fully designed and scheduled to take place, however a change in the presidential administration led to the cancellation of the project. We include this project to demonstrate the diversity of topics covered and federal agencies engaged, and to highlight the sometimes politically unstable nature of this work.

[3] Deliberations listed as "stakeholder only" did not include members of the general public as participants. These projects helped us refine the processes later used in our stakeholder design workshops (further described below).

[4] Though we distinguish between experts and stakeholders for clarity, we recognize that stakeholders have their own form of expertise. While what we define as "experts" primarily offer *contributory expertise* (expertise to contribute to the science of a field), stakeholders have *interactional expertise* (an understanding of the context and community in which work is being conducted) (Evans & Collins, 2002). Of course some individuals might have both forms of expertise. We draw on both types of expertise throughout our process.

**Table 1**
ECAST network's portfolio of participatory technology assessment projects.

| Year | Subject | Scale | Key Sponsor(s) | Locations (Participants) |
|---|---|---|---|---|
| 2012 | Biodiversity | National, Global | United Nations Convention on Biological Diversity | 4 (277) |
| 2014 | Planetary Defense | National | National Aeronautics and Space Administration | 2 (186) |
| 2015 | Climate and Energy | National, Global | United Nations Framework Convention on Climate Change | 4 (275) |
| 2015–2018 | Climate Resilience | Local | National Oceanic and Atmospheric Administration (NOAA) | 8 (489) |
| 2016–2017 | Nuclear Waste Disposal | National | Department of Energy | 5 (canceled)[2] |
| 2016–2017 | Genetically Modified Algae | National | Environmental Protection Agency | stakeholder only[3] |
| 2016–2019 | Gene Drive Mice | National | Defense Advanced Research Projects Agency | stakeholder only |
| 2017–2018 | Driverless Cars Issues | Local, National | Kettering Foundation | 2 (23) |
| 2017–2019 | Climate Intervention Research | National | Sloan Foundation | 4 (202) |
| 2018–2019 | Automated Mobility Futures | Local, National | Charles Koch Foundation & Alfred P. Sloan Foundation | 4 (317) |
| 2018–2020 | Future of Internet Pilot | National | Internet Society | 1 (32) |
| 2020–2020 | We, The Internet | National, Global | Internet Society, UNESCO, World Economic Forum, European Commission, World Wide Web Foundation, others | 5 (55) (virtual) |
| 2018–2021 | Climate Resilience and Citizen Science | Local | NOAA | 28 (planned) |
| 2018–2022 | Community Co-creation | Local | National Science Foundation | 4 (planned) |
| 2019–2020 | Public Interest Technologies | Local | New Venture Fund (Public Interest Technology University Network) | 4 (201) (virtual) |
| 2019–2020 | Human Gene Editing Issues | Local, National | Kettering Foundation | 2 (43) (virtual) |
| 2019–2022 | Human Genome Editing Futures | National | National Institutes of Health | 3 (planned) |

subsequently allow conflicting parties to put forth opposing scientific evidence to support their positions (Sarewitz, 2004). Take, for instance, quintessential post-normal issues such as genetically modified organisms and nuclear energy and waste disposal. Despite years of scientific research, political conflict surrounding these issues remain as contested as ever, if not more so.

Such contentious problems both proliferate within, and characterize, an age of divisive politics. New methods for helping legislators and other decision makers anticipate the social aspects of emergent technologies

**Table 2**
Clarification of terms used throughout the paper.[4]

| | |
|---|---|
| **Experts** | Individuals who study the science or technology at the core of a given sociotechnical question. These include physical and natural scientists, engineers, and other professionals who are conducting technical research or developing a technology. Also included are social scientists, humanists, and other scholars studying the societal impacts of a given science or technology, as well as federal agency officials who play roles in shaping technical knowledge and how it's used. |
| **Stakeholders** | Actors from government, nongovernmental organizations, philanthropies, and industry who are not directly involved in the development of a technology but still view themselves as having a stake in the outcomes. We distinguish these stakeholders from members of the general public. These actors already have formal pathways for shaping decisions around sociotechnical issues through advocacy groups, lobbying, or other political channels. |
| **Citizens** | Members of the general public with no formal stake in an issue. Use of the term "citizen" does not relate to an individual's legal citizenship status, but rather emphasizes the individual's role as a non-expert actor in a democratic society. |

and manage them upon arrival are a critical need in democratic decision-making. One general category of approach is technology assessment (TA), the "practice intended to enhance societal understanding of the broad implications of science and technology" (Sclove, 2010). New capabilities such as the Science, Technology Assessment, and Analytics (STAA) team at the Government Accountability Office are taking a leading role in conducting these assessments (NAPA, 2019). But modern TAs require an upgrade from their twentieth-century predecessors, which primarily sought to produce technical inputs to policy problems. Traditional TAs failed to capture many of the social and ethical considerations surrounding technical questions, thus limiting their usefulness to decision makers. Future TAs that address ethical dimensions and call attention to structural social impacts may better equip policymakers to address emerging technologies (Graves and Cook-Deegan, 2019; Sclove, 2020; Smits et al., 2010).

Modern TAs also need to be better integrated into institutional decision-making processes. Critiques of the 1990s Ethical, Legal, and Social (ELSI) programs of the US Human Genome Project assert the "impotence" of the programs due to their organizational separation from actual research decision-making (Fisher, 2019, 2005; McCain, 2002). This fate similarly befalls many ELSI reports produced by National Academies committees, executive-branch bioethics commissions, and congressional research units. One promising attempt to address this problem is the 21st Century Nanotechnology Research and Development Act of 2003, which prescribed integration of societal and technological concerns into both research and research policy processes (Fisher and Mahajan, 2006). The Act also called for public input and outreach, types of involvement that Sclove (2020) asserts may provide better insights into structural-level impacts of technologies than individual concerns raised by ELSI experts.

How might one rethink science and policy in a post-normal age? Funtowicz and Strand (2007) summarize different theoretical frameworks for approaching the relationship between science and policy, such as cost-benefit and precautionary approaches, and show why these typically fail to address a core challenge of the post-normal age: the values controversies that lie beneath apparently technical debate remain unresolved.

Such controversies arise from the differing ways individuals and institutions assess the relevance of an issue and their beliefs about how to address, or even think about it (Schwarz and Thompson, 1990). For example, how much value should be given to a human life in a cost-benefit analysis? What risks might one accept in exchange for what potential benefits? What social disruptions are acceptable and for whom? For such values questions and tradeoffs, Funtowicz and Strand (2007) propose an extended participation model to help make explicit what is often unacknowledged by experts or decision makers. In the model, an extended peer community of citizens serves as “critics and creators in the knowledge production process” (Funtowicz and Ravetz, 1993b; Funtowicz and Strand, 2007). Exploring this idea further, we can see how citizen engagement can improve both the outcomes of scientific research and its integration into decision-making.

Citizens can introduce an expanded variety of perspectives on how scientific questions should be framed (Kitcher, 2001). No singular perspective would then dictate the direction of inquiry. Citizens would also weigh in on the strength and relevance of scientific evidence throughout the decision-making process. Ultimately broader inclusion of citizens generates more “socially robust” knowledge because society was involved in the genesis of the knowledge and the knowledge assessment process (Gibbons, 1999; Nowotny et al., 2001). Generation of socially robust knowledge can: 1) lead to greater trust in scientific knowledge and attenuate future controversy (Kitcher, 2001), 2) yield new insights and ideas that ultimately improve technological design (Schwarz and Thompson, 1990), 3) help citizens feel more ownership of or investment in issues (Fischer, 2000), and 4) expand society’s ability to manage emerging technologies (Guston, 2011). Not all methods of citizen engagement, however, yield these positive outcomes.

Chilvers and Kearnes (2020) attribute such shortfalls for one type of engagement, citizen deliberation, to what they describe as the “residual realist” view of engagement that treats citizen deliberation and its evaluation as predefined, fixed concepts. This inflexible approach is not suitable for deliberation work in practice, especially in evolving political and social contexts. As an alternative, Chilvers and Kearnes (2020) offer a framework that outlines paths to forge reflexive participatory practices, situate participation within broader decision contexts, encourage innovations in participatory democracy, and recognize the impacts of science and society on the deliberation. In reflecting on the evolution of ECAST and its work over the past decade, we find that we followed many of these paths while working to translate the vision set out at the network’s founding to something that could work in actual decision-making settings. Both the network’s structure and pTA method serve to incorporate new voices and visions into science and technology decision-making through a reflective practice-oriented approach. In the following section, we detail the current state of our pTA method with the hope that others will continue to innovate on it, advancing reflexive citizen deliberation as means of democratic decision-making.

## 3. Three participatory activities

Our pTA method includes three phases of participatory activity: 1) Problem Framing; 2) ECAST Deliberations; and 3) Results and Integration (Fig. 1). While presented as distinct phases, pTA is actually an iterative process. Projects typically span between 18 months and three years depending on their scale.

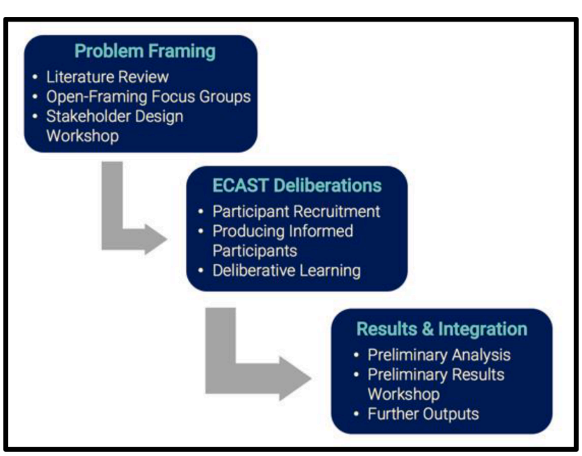


**Fig. 1.** The three phases of the ECAST pTA method with their key activities.

The novelty of our method stems not from the development of all new tools for deliberation and engagement, but rather through its integration and reflexive adaptation of existing methods to increase the diversity of voices involved in TAs. Multiple approaches exist for eliciting expert and stakeholder perspectives (Jones et al., 2011), conducting dialogues with citizens (Rowe and Frewer, 2005), and presenting results to decision makers (e.g., briefs, reports, journal articles). Our method builds on and connects these discrete science policy activities to support inclusive, deliberative, and usable TAs. Since 2010, we have reflexively co-designed engagement tools with the public, experts, and stakeholders that adapt pTA forums to local circumstances (Chilvers, 2008; Chilvers and Kearnes, 2020; Pallett, 2015) and uniquely respond to institutional and cultural contexts.

### 3.1. *Problem framing*

Our method uses two participatory activities to construct a balanced issue framing. Recognizing that public concerns may not always align with those of experts (e.g., Jasanoff, 2003; Wynne, 1996) and that an expert-designed series of questions can merely reinforce pre-existing expert commitments (Stirling, 2008), we begin our issue-framing process with open-framing focus groups (e.g., Bellamy et al., 2016), which empower citizens to speak through their experiences. We then combine citizen perspectives with expert and stakeholder perspectives extracted from a prior review of the academic literature and from a stakeholder design workshop. Prior to our full-scale deliberations, we conduct a small test deliberation and make necessary adjustments to the design and materials to improve their clarity.

#### 3.1.1. *Open-Framing focus groups*

We recruit diverse groups of 15–20 citizens for open-framing focus groups in two to three locations. These focus groups use a two-tiered deliberation model—occurring either on one full day or two half-day sessions—to elicit both unstructured (tier 1) and structured (tier 2) responses. The first tier includes open-ended questions on general hopes and concerns regarding the topic (Rourke, 2014). Participants receive minimal background material during the first tier and instead draw on their personal experiences to inform their responses (Bellamy et al., 2016; Parkhill et al., 2013, p221). Beginning with a loose structure around the topic also allows us to gauge the relationship between the issue and its social context (e.g., for driverless vehicles, we begin with broader transportation issues) and reveals which issues participants prioritize most (Macnaghten, 2017). The second tier introduces subject-specific background material, expands on themes from first-tier discussions, and maps them against issues identified in the academic literature review. While the first tier allows citizens to reflect freely and personally without expert framing, the second tier offers additional reflections on issues not previously considered by participants. The second tier thus serves as a check on how much framing influences public perspectives and guides our approach to the general deliberation design.

#### 3.1.2. *Stakeholder design workshop*

The purpose of the stakeholder design workshop is to solicit guidance from experts and stakeholders on the design of our citizen deliberations. The workshop supports four main goals: 1) determine how to frame the policy problem from a diversity of perspectives and gauge the trade-offs and levels of uncertainty associated with different plausible responses (Pielke Jr, 2007); 2) understand what basic knowledge is necessary for informed public input; 3) identify what sociotechnical questions from the expert perspective could benefit from public deliberation (Stirling and Mayer, 2001); and 4) ask experts and stakeholders to reflect on citizen responses from the open-framing focus groups (Bellamy et al., 2016). We use these perspectives and reflections, along with the outcomes of the open-framing exercises, to inform the questions, structure, and background information for the pTA forums.

When inviting experts and stakeholders to the workshop, we are less concerned with filtering out individuals who may be operating as advocates or "stealth advocates" (Pielke Jr, 2007), than with assuring that our set of participants adequately represents the multifarious views and positions for a given issue. A range of expert and stakeholder views helps to assure that contested facts and values, and ongoing uncertainties, are not suppressed through an artificial commitment to lowest-common-denominator consensus positions or supposedly neutral appeals to unresolved uncertainties. We use these diverse expert and stakeholder perspectives and reflections, along with the outcomes of the open-framing exercises, to inform the questions, structure, and background information for the pTA deliberations, striving for an overall balanced design. After the workshop, we construct an expert review committee that represents diverse backgrounds and perspectives. These experts later review and provide feedback on the background materials and deliberation design and may also answer questions during the ECAST deliberations.

### 3.2. ECAST deliberation

Derived from the Danish Board of Technology's day-long, 100-person World Wide Views (WWViews) method of multi-site deliberation (Danish Board of Technology, 2012), the following paragraphs describe the method with which we elicit public values and preferences, which we define as an ECAST deliberation.

#### 3.2.1. Participant recruitment

Our pTA citizen deliberations bring together approximately 80–100 diverse members of the public that represent a cross-section of the population of the city or state in which the deliberation takes place. In order to achieve sufficient diversity with respect to age, ethnicity, education level, and other topic-specific criteria of relevance (e.g., for the project on driverless mobility, the primary mode of transportation), we recruit participants through email lists, social and traditional media, institutional partnering, and face-to-face canvassing, and offer a stipend, usually $100.[5] We do not make any claims of, nor do we prioritize, statistical representation. While census data guide our recruitment, we ultimately strive for diversity and inclusion, bringing together representatives of each demographic group within the subject population to promote a plurality of perspectives (Dryzek, 2012).

We work to limit participation of individuals who are actively involved in the topic by profession or through advocacy as their views (or those of people like them) are already known through processes such as lobbying, public commenting, and town halls. They are also more likely to dominate the conversation due to their higher levels of technical knowledge and personal conviction (Kerr et al., 2007). The construction of a "disinterested public" offers opportunities for decision-makers to hear new perspectives on an issue (Felt and Fochler, 2010; Sclove, 1995).

#### 3.2.2. Producing informed participants

We design our citizen deliberations in the style of what Kitcher (2001) describes as "tutored" deliberations. As further defined by Durán and Pirtle (2020), tutored deliberants have an understanding of the historical significance and values surrounding a question and feel ready to debate a given issue. To promote thoughtful dialog, we brief participants on the technical aspects, salient issues, questions, and areas of uncertainty related to the topic. Participants receive an information packet two weeks prior to the deliberation. Themed videos, multi-media presentations, and briefing materials introduce additional information and considerations. These briefing materials include "stakeholder cards"—cards with short descriptions of issue experts' and stakeholders' perspectives, and common public concerns derived from the open-framing focus groups and the design workshop. In some of our projects, we included experts during the deliberation activity in a limited and mediated (no direct interaction with participants) fashion to answer participants' questions.

Even though the expert review committee checks that the presented materials are balanced and accurate, we recognize that briefing participants inevitably introduces some level of framing effects. We also acknowledge that curation of the briefing materials involves value judgements regarding what information is essential to avoid overwhelming participants with information (Duncan et al., 2020). We rely on feedback from the stakeholder design workshop and our expert review committee to determine this balance and seek to mitigate potential bias in two ways: 1) Viewing the outcomes of the ECAST deliberations in light of the open-framed (un-briefed) focus group responses, and 2) Using notes from table observers to understand the ways in which participants draw on or reference the briefing materials.

Observations from past forums found that participants did often reference the briefing materials and that the quality of discussion, even for highly technical topics, was high (Kaplan et al., 2019; Tomblin et al., 2017). We attribute some of the successful integration of briefing materials to our partnerships with informal science educators and their expertise in designing accessible education materials. Despite the challenges with briefing participants, we feel that doing so is essential to combat criticisms that members of the public simply do not understand the underlying technical issues. Our briefing process aims to "inform" rather than "educate," distinguishing it from both public communication and consultation (Rowe and Frewer, 2005).

#### 3.2.3. Deliberative learning

On the day of the deliberation, participants sit at tables of 6–8 individuals with a neutral facilitator who guides them through multiple thematic sessions. For multi-site deliberations, all sites use the same materials and facilitation protocol. All sessions are common across sites, with the exception of one. The exception is a "local session" that is unique to each location and dedicated to local issues. The general format for each session is: 1) watch a short briefing video, 2) engage in an interactive and facilitated table discussion regarding the session topic, and 3) complete a group activity and individual worksheet. We host the deliberations at science museums, universities, or similarly neutral locations so that participants feel the deliberation process is independent of political influence.

### 3.3. Results integration

#### 3.3.1. Research outputs and analysis

We collect both quantitative and qualitative data regarding public values and rationales. Qualitative data include written rationales from group activities and individual worksheets and notes from table observers. In projects for which we have sufficient funding, we also create transcriptions of table audio recordings. We analyze these qualitative data using standard open and thematic coding methods (Braun and Clarke, 2006; Evans and Kotchetkova, 2009; Strauss and Corbin, 1990). Open coding helps us identify emergent issues derived from deliberation dialog and written rationales (e.g., Macnaghten et al., 2019; Wibeck et al., 2015). Table observations specifically help guide the open coding by identifying broader reasoning patterns and by developing public value maps that reveal emerging, unanticipated issues (Bellamy et al., 2017; Lezaun et al., 2017). We employ thematic coding to analyze the extent to which participants are engaging with issues identified in the open-framing focus groups and design workshops, and to identify themes of expressed interest to decision-makers.

Quantitative data collection tools include pre- and post-surveys—which assess motivations for participation, overall procedural satisfaction, self-perceived attitude change, and knowledge acquisition as a

[5] Though some studies (detailed in National Research Council, 2013) suggest that stipend incentives may affect the responses research participants provide, we found that offering a stipend was critical for recruiting a sufficiently diverse participant sample.

result of participation (Rask et al., 2012)—and Likert-scale ratings (five or seven point scale ratings expressing level of agreement or disagreement with a statement) and rankings on individual worksheets. We conduct basic quantitative analysis on these data, calculating means and distributions, as well as two-sample t-tests (or ANOVA analysis) to compare means between sites. We do not use these analyses to make any statistical extrapolations from our participant groups to the population at large. Our statistical work is only to make sense of the data generated by the deliberations and to provide a general assessment of the forum. We use the aggregate profiles of participants at each site to help explain why different sites might generate different perspectives on an issue. The profiles also help us identify demographic differences in perspectives about an issue, which is useful in thinking about how decision-making has differential impacts along socioeconomic, educational, gender, and ethnic lines (e.g., Williams and Woodson, 2019).

#### 3.3.2. *Preliminary results workshop*

During the deliberations, we collect more data than we can analyze within the project timeframe. We use a second workshop with issue experts and stakeholders to present preliminary deliberation results and to solicit input on directions for further inquiry. This workshop serves as the third participatory element in our pTA process. While we strive to generate usable input that stakeholders find credible, salient, and legitimate (Cash et al., 2003), these workshops also become an opportunity to take experts and stakeholders beyond what they normally accept as usable data (Bellamy et al., 2013). For instance, the use of qualitative data in decision-making can be unfamiliar to technical decision-makers. These workshops become first encounters with this type of data, allowing for reflective exploration about what it means and how it can be used in decision-making. Through this process, experts and stakeholders begin to expand their views of the value of citizen input into decision-making (see NASA example below; Tomblin et al., 2017). These workshops are also an opportunity for us to be reflexive about the framing, design, implementation, and potential future expansion of the pTA deliberations (Chilvers, 2008; Chilvers and Kearnes, 2020).

#### 3.3.3. *General outputs*

We aim to generate outputs that: 1) more expansively evaluate the technical, social, legal, and ethical dimensions of emerging science and technology issues, 2) encourage expert and stakeholder reflexive engagement with emerging issues, 3) are useful to local and national policy and decision-making processes (Delborne et al., 2013; Emery et al., 2015) 4) empower citizens and promote broader societal dialogues on the issues, and 5) improve subsequent framing, design, and implementation of future pTA forums. To that end, we disseminate our results in multiple formats. In addition to producing peer-reviewed publications, we share pTA outputs via reports and briefing presentations to decision-makers, potential future pTA deliberation hosts, participants, and the broader public.

## 4. Mini cases – innovation and learning

At the network's inception, we set out to operationalize the five core ECAST objectives strategically and opportunistically, maintaining a sensitivity to political openings and closings (i.e. when decision-makers have interest in and resources for citizen input) (Chilvers and Longhurst, 2016). The decision to use the World Wide Views (WWViews) method of deliberation, opportunistic at the time, turned out to be strategically significant. Over the course of subsequent projects, the method proved sufficiently agile, scalable and adaptable for addressing diverse science and policy issues. We present here brief summaries of our initial demonstration project and five succeeding projects that show how we reflexively and iteratively modified our pTA method through continuous conceptual and methodological innovations.

### 4.1. *World Wide Views on Biodiversity*

Background: WWViews on Biodiversity was a global citizen consultation held in 25 countries on September 15, 2012. Designed and developed by the Danish Board of Technology (DBT), the consultations provided input to the Eleventh Council of Parties of the United Nations Convention on Biological Diversity. DBT trained the global partners on their WWViews method and provided the deliberation design and materials. On the deliberation day, results from all of the countries were uploaded to a website and were later analyzed and synthesized into a results report for presentation to national and global bodies.

Process: We used WWViews on Biodiversity as a demonstration project for the ECAST network, hosting deliberations in Boston, Denver, Phoenix, and Washington, DC. To showcase the distributed network model, each site featured institutional partnerships between a university and an informal science education center.

Learning: From this initial project we drew important lessons that expanded the ECAST concept and spurred the development of our pTA method (Worthington et al., 2012):

1. **Actively engaging policy stakeholders**: Future efforts needed to broaden, systematize, and integrate expert and stakeholder engagement into the design, deliberation, and dissemination processes.
2. **Training for museum professionals**: Educators in science centers required training on the concepts and practices of citizen deliberation.
3. **Integrated research and evaluation**: Research and evaluation needed to be an integral part of the designed activities, not an afterthought.
4. **Improving participant recruitment**: The citizen recruitment process required improvement by pre-screening citizens, paying a stipend, and partnering with community organizations in order to meet our representative diversity and process legitimacy goals.
5. **Capturing participant narratives**: Participants should be able to express their views using their own words—beyond the standard predetermined multiple-choice options designed by experts and stakeholders.
6. **Exploring executive branch opportunities**: Future pTA projects should leverage the citizen engagement component of the Open Government Initiative[6] to create partnerships with federal agencies.

We applied these lessons to our next pTA project, sponsored by NASA.

### 4.2. *Informing NASA's asteroid initiative*

Background: In July 2013, NASA released a request for information on innovative ideas to facilitate planning of the agency's Asteroid Initiative. We submitted a response recommending that NASA engage citizens via WWViews-style deliberations. We later entered into a cooperative agreement with NASA to design and conduct two in-person and one online citizen deliberations. The deliberations would collect informed citizen views on the Asteroid Initiative; provide citizen views as an input to shape the Initiative's direction and engagement activities; and serve as a potential pilot for pTAs of NASA's future science and technology initiatives.

Process: The cooperative agreement represented a departure from a standard federal agency research grant. The nature of the agreement, which required that NASA remain involved, fostered collaboration on the deliberation design. The project also provided an opportunity for us

[6] During his presidency, President Obama called for greater transparency and public involvement in federal decision-making in his Memorandum on Transparent and Open Government (Transparency and Open Government; Memorandum for the Heads of Executive Departments and Agencies, 2009).

to follow-up on all six of our WWViews Biodiversity lessons learned and innovate on the WWViews method. We first instituted tighter screening to limit space experts and advocates. Second, NASA sought to understand the reasoning processes that participants used in arriving at their individual and group selections. We altered the WWViews deliberation design, adding collection of qualitative data via written rationales for individual and group votes, notes from table observers, and transcripts of table audio recordings to meet this need. These qualitative data allowed us to construct narrative descriptions of table discussions. NASA program managers found these narratives beneficial for countering criticisms that citizen preferences for one technology pathway over another stemmed from a lack of understanding. As a third innovation, we promoted more active engagement during the deliberation by introducing several discussion aids and group activity boards. Fourth and finally, NASA experts participated in the deliberation through a mediated and virtual expert question and answer session.

Learning: The most important lesson from the NASA project was that active engagement of experts and stakeholders throughout the pTA process increases the usability of the pTA outcomes. This active engagement was a reflexive co-learning process. Through consistent communication with NASA experts, we were able to better understand the types of citizen input data that they found most valuable and NASA experts expanded what they considered valuable citizen input (e.g., the integration of qualitative data). Aiming to foster a similar dynamic around the analysis of our pTA data in future projects, we decided to add what we later called a preliminary results workshop to our method.

The deliberations provided direct input on NASA's 2014 Asteroid Redirect Mission Downselect Decision which weighed tradeoffs between two methods for capturing an asteroid. In deliberation, participants expressed a nearly unanimous preference for the option that included as a co-benefit the social values of developing technology for future voyages to Mars and advancing planetary defense (Tomblin et al., 2015). NASA ultimately chose to move forward with this option. While their decision was grounded in many technical factors, we do know that feedback from our pTA method was included in their decision process and that citizens' preferences were consistent with NASA's final choice (Steitz, 2015). Furthermore, the deliberations helped elevate the issue of planetary defense within NASA's discourse. In a public event in March 2018, a NASA official stated that participants' strong emphasis on planetary defense during the deliberations influenced the creation of NASA's Office of Planetary Defense in 2015 (ASU, 2018). The meaning behind this action is twofold—it first demonstrates that members of the public can exercise foresight when considering future priorities that may not be the current focus of the technical community; and secondly, agency decision-makers can successfully integrate unexpected input from deliberations.

Nevertheless, though active engagement with NASA experts led to mutual learning and influenced decision-making within some of NASA's directorates, we realized that the framing of the pTA was narrowly construed through NASA's priorities. Based on our experience with NASA, we subsequently sought to systematize sustained engagement with experts, but also expand our pTA design to include a broader set of stakeholders.

### 4.3. Community deliberation for improved resilience and environmental decision-making

Background: During the NASA project, we improved upon many elements of our pTA method but did not address our goal of implementing training for museum professionals. We viewed museums as essential partners because of their convening power, status as a nonpolitical institutions, and knowledge of local context. Though museums traditionally focus on exhibit-based work, we sought to develop their capacity to host deliberations. An opportunity to do so emerged with a request for proposal (RFP) from NOAA's Office of Education in Spring of 2015. The RFP argued that in order for communities to become more resilient, "their members must have the ability to…weigh the potential impacts of their decisions systematically" ("NOAA-SEC—OED-2015–2,004,408," 2015). We saw this as an opening to demonstrate how informed citizen deliberation could be used as a replicable model for strengthening community resilience while generating capacity within science museums to conduct pTAs.

Process: The first year of the three-year project focused on systematic and structured expert and stakeholder engagement to design the deliberation, including the local sessions. This process innovation grew out of critiques of narrow, expert framings like that in our NASA project. We held workshops in Boston and Phoenix, bringing together not only NOAA experts but also local resilience planners and stakeholders. We piloted our pTA method in two museums and then replicated it in six additional museums in the United States. The Museum of Science, Boston, a founding ECAST member, hosted the first deliberation and leveraged the event as a training opportunity. In addition to learning about the logistics of recruiting for and hosting a deliberation, the event managers and lead facilitators for future host-sites were able to actually witness the execution of a pTA deliberation.

Learning: The key lesson for us was that museum teams can quickly develop capacity to host deliberations using centrally-developed materials. This increased capacity, in turn, adds value to pTA projects by providing additional locations where pTA practitioners can host deliberations, ideally adding geographic diversity to the deliberation sites. One noteworthy difference between the NASA and NOAA projects was the scope. While the goal of the NASA project was to provide mission-level decision support, the NOAA project sought to develop local capacity for resilience planning. Results integration was not part of the NOAA project scope and was left to the initiatives of the local planning authorities. Some planning authorities used the results but many did not. We believe that through more sustained engagement with our pTA process, the planning authorities may have had greater trust in the method and seen value in the developed materials as tools to support their educational and engagement goals. Nevertheless, NOAA saw value in our deliberative approach and provided a follow-up grant to our partner, the Museum of Science, Boston in 2018 (Table 1) to replicate the model and apply lessons-learned in 20 additional cities.

### 4.4. Open-Framing on autonomous vehicles

Background: In late 2016, the Kettering Foundation, a research organization that studies approaches for promoting democratic principles, invited us to a series of meetings about improving methods of citizen participation. During the meetings, we highlighted two specific areas for improvement based on our project experiences: rural representation and expert framing. Primarily hosting our deliberations in major urban centers, we acknowledged our failure to capture hopes and concerns of individuals living in rural areas. We also recognized that only engaging experts and policy stakeholders in the design and development of our deliberation topics and questions may alienate citizens during deliberation. If citizens do not see their concerns reflected in the issue framing, they are apt to lose interest and disengage from the process (Bellamy et al., 2016; Rourke, 2014). By only speaking with experts and stakeholders, we might also fall victim to blind spots in emergent areas of concerns and fall short in one of the main goals of public deliberation: citizen empowerment. We partnered with Kettering in the spring of 2017 to conduct a design experiment. We sought to explore how citizen framing of emergent technology issues might differ from those of experts and stakeholders. Using autonomous vehicles (AVs) as the issue of focus, we used an open-framing approach—providing minimal background information on AVs—to explore citizens' hopes and concerns in a small, rurally situated city (Cumberland) and an urban center (Baltimore) in Maryland.

Process: Traveling to each city twice over the course of four weekends, we solicited both unstructured and structured responses from open-framing focus group participants. During the first week's discussion we asked participants their hopes and concerns about transportation and automatiion, and the hopes and concerns of their friends and family. The second week we introduced areas of expert concern that participants had yet to discuss. Participants then shared additional points of concern in light of the new information. We used the insights derived from the focus groups to create an issue guide about AVs for the National Issues Forums (Lloyd et al., 2018).

Lessons Learned: We were surprised that over the course of their discussions participants touched on many of the issues we had identified during our literature review and also introduced interesting new concerns. Though participants shared many of the same concerns as experts, the relative priorities of those concerns differed between the two focus groups and between citizens and experts. We found that the open-framing design created space for personal narratives to surface. The focus groups also revealed that public concerns often extend beyond monetized valuation continuums (e.g. lives saved, pollution avoided, and traffic reduced) characteristic of choice sets in structured deliberations. This experiment convinced us of the value of flipping our design process to begin with public concerns as a means of generating alternative issue framings than those of experts. We incorporated this process innovation in our subsequent projects on climate intervention research, a second project about autonomous vehicles, and a project on human genome editing.

### 4.5. *Deliberations on climate intervention research*

Background: Climate intervention research involves high uncertainty, expert disagreement, and contested values—especially for a class of methods called Solar Radiation Management (SRM) which aim to change the earth's heat balance by reflecting more sunlight back into space (National Research Council, 2015). In early 2017, a group of scientists from Harvard University announced their plans for a field experiment to study a potential SRM method (Dykema et al., 2014). Aware of possible public concern and opposition, the Harvard team approached us about conducting a deliberation on their proposed research. We were wary of using deliberation as a means to increase public acceptance of a contested research project. Instead, we recommended developing a broader pTA deliberation inclusive of the perspectives of proponents and opponents of the general prospect of SRM research. After discussions with multiple philanthropic organizations, we secured funding from the Alfred P. Sloan Foundation to conduct pTA deliberations in two cities on democratic governance of SRM research.

Process: As an exploration of general SRM research governance, this project lacked a direct tie to a specific decision process. We instead targeted the project outputs at three primary audiences: scientists working on SRM research, funders who might support SRM research, and scholars and practitioners engaged in developing governance frameworks for SRM research. We also introduced the preliminary results workshop to support integration of pTA outputs into expert and stakeholder decision processes. The project thus represented the first manifestation of our full pTA method (Section 3). In designing a broader pTA deliberation, we chose to include an option wherein participants could choose not to pursue SRM research. This option sought to address the underlying question of "should we or should we not?" and give citizens the choice to say no to conducting SRM research (Lehtonen, 2010). We also included a "we should not" option in our later project about autonomous vehicle development.

Lessons Learned: The decision to broaden the scope of the pTA and situate it independent of the Harvard research project yielded the desired outcomes of greater methodological rigor and political legitimacy. This independence, however, came with a tradeoff in terms of output usability and influence on decisions. In the NASA project, the pTA outputs were directly integrated into agency decisions. In the NOAA project, local experts and decision makers could learn from their direct involvement. Given the SRM project's broad target audiences and lack of focus on one specific research or technology development project, producing a traceable impact in a similar timeframe was not possible. This experience exposed the tension between the theory and practice of participatory deliberations, between being embedded and being independent, and between process legitimacy and impact on decision processes (e.g., Lehtonen, 2010; Stilgoe et al., 2014; Stirling, 2008). We feel that this tension requires further discussion and debate amongst deliberation practitioners.

### 4.6. *Automated vehicle futures*

Background: After encountering differing expert and citizen framings of AVs during our 2017 Driverless Cars Issues project, we recognized the need for further deliberation on the subject. Missions Publiques, a French nonprofit that organizes citizen deliberations and a prior project partner of ours, was simultaneously in the midst of organizing day-long deliberations on AVs in five French cities. In collaboration with Missions Publiques, we developed a plan to host deliberations on automated vehicles in 17 cities across nine countries in Europe, the United States, and Asia. In the U.S., we used philanthropic support to design and host deliberations in Boston, Washington, and Phoenix in May of 2019. We also invited other cities to use our design and deliberation materials to host a deliberation with their own funding. Several cities expressed interest and ultimately Buffalo, NY convened the fourth U.S. forum in August 2019.

Method: We adapted our pTA method to respond to the rapidly shifting socio-political context of AVs. This included developing a broad partner coalition (e.g., project partners included Audi, U.S. Federal Highway Administration, American Public Transportation Association) within the U.S. to better understand diverse expert and stakeholder perspectives on AV development and what questions could benefit from citizen deliberation. This project involved all three participatory activities of our pTA method and brought back use of a local session (not relevant in some of the previous projects) designed in collaboration with local members of the partner coalition. By hosting the deliberations over many months, new cities could join the project based on their individual policy or programmatic windows.

Lessons Learned: Building a partner coalition takes time, patience, and perseverance. We required almost a year to identify and train cities to host the four deliberations. Partners that were proactive and willing to invest their own resources hosted more successful deliberations. The Greater Buffalo Niagara Regional Transportation Council, which hosted the Buffalo deliberation, directly utilized the results from their local session to guide its strategic planning for automated vehicles.

Deliberations on emerging technologies are not well-suited for the standard format for grant-funded projects with set dates and deliverables since they rely heavily on social and political windows of opportunity. These projects also require an especially flexible approach to the pTA method since the issue context changes rapidly. When we began this project, the deliberation outputs seemed most relevant to transportation planning agencies. Through sustained interactions with experts and stakeholders, we ultimately found that the deliberations generated outputs of greater interest to industry members. This project also served as a validation that our pTA method is both structured enough to allow it to be replicated, and flexible enough to be applied at various scales, ranging from the local to the global scales. The unique design elements added during this project, as well as those discussed in the other mini cases, are summarized in table 3.

## 5. Discussion and future research

Social science literature has explored and expounded upon the ideas of responsible innovation, technology assessment, and anticipatory governance as means of promoting positive societal outcomes in a post-normal context (Barben et al., 2008; Parkhill et al., 2013; Sclove, 1995; Stilgoe et al., 2013). Our pTA method offers one approach for operationalizing these theories via citizen deliberation. Translating these

**Table 3**
Table comparing design elements from mini case projects.

| | Design Element | World Wide Views on Biodiversity (2012) | Informing NASA's Asteroid Initiative (2014) | Community Deliberation for Improved Resilience and Environmental Decision-Making (2015–2018) | | Deliberations on Climate Intervention Research (2017–2019) | Combined Automated Vehicle Projects (2017–2019) |
|---|---|---|---|---|---|---|---|
| Problem Framing | Literature review | ✓ | | ✓ | | ✓ | ✓ |
| | Consultations with experts | ✓ | ✓ | ✓ | ✓ | | ✓ |
| | Co-design with project sponsor | | ✓ | | | | |
| | Expert committee | ✓ | ✓ | ✓ | ✓ | | ✓ |
| | Stakeholder design workshop | | | ✓ | ✓ | | ✓ |
| | Open-framing focus groups | | | | ✓ | | ✓ |
| | "We should not" option | | | | ✓ | | ✓ |
| | Multi-sectoral coalition | | | | | | ✓ |
| Deliberation | Expert Q&A | | ✓ | ✓ | ✓ | | |
| | Training for museum professionals | | | ✓ | | | |
| | Active engagement (discussion aids, group activity boards) | | ✓ | ✓ | ✓ | | ✓ |
| | Local session | ✓ | | ✓ | | | ✓ |
| Results & Integration | Quantitative data | ✓ | ✓ | ✓ | ✓ | | ✓ |
| | Individual responses | ✓ | ✓ | ✓ | ✓ | | ✓ |
| | Qualitative data | | ✓ | ✓ | ✓ | | ✓ |
| | Group responses | | ✓ | ✓ | ✓ | | ✓ |
| | Preliminary results workshop | | | | ✓ | | ✓ |

theories into the policy and practice domains inevitably creates a tension between methodological rigor and practicable and understandable procedures. Through a process of "ongoing experimentation" (Lövbrand et al., 2011), we aspire to the principles of good practice established at the ECAST network's founding while working to meet the needs of democratic decision-makers. The products of our decade-long experiment—our pTA method and the ECAST network itself—offer not only a resource for practitioners of democratic decision-making but also an institutional memory of lessons learned.

One of the main lessons is that our pTA method proved extremely adaptable. This adaptability allowed us to incorporate new elements based on developing academic theories and changing policy contexts. We built on the WWViews model, adding additional participatory activities to address concerns regarding expert-only framings and to develop relationships for improved decision impact (Delborne et al., 2013; Emery et al., 2015). Further, we found that timing the deliberations based on policy windows rather than predefined project timelines created more opportunities for citizen deliberations to support decision-making. Perhaps most importantly, we grounded our method in a focus on reflexivity (Chilvers and Kearnes, 2020; Stilgoe et al., 2013). Treating each pTA as a reflexive research project, we built upon our lessons learned and embraced change in the face of evolving political, social, and institutional contexts (Guston, 2011). We feel that the adaptability, flexibility, and reflexivity embedded in our three-phase model allow for navigation of the delicate balance between policy and practice.

Operationalizing principles of democratic decision-making through a distributed network offers unique advantages. ECAST's distributed structure brings together a breadth of expertise beyond the scope of one organization. The projects benefit from the partners' diverse experiences with engagement, academic research, and policy translation and the partners learn from one another through the collaboration process. ECAST partners then transfer what they have learned to the next project. In other words, there is knowledge generation, absorption and internalization leading to iterative innovation and improvement, just as would be the case with a learning organization (Senge, 2006).

Many deliberation methods emphasize the impacts of the experience on participants. While important, we are also interested in exploring the impacts on the experts, stakeholders, and conveners involved with pTA deliberations. Our experience and project-specific evidence suggest this process of co-design helps promote a new way of "seeing participation" (Chilvers and Kearnes, 2020) that extends beyond a deficit model view of public engagement wherein public distrust of science stems from a lack of understanding (The Royal Society, 1985). To expand our project-specific evidence of organizational impacts of pTA, we are working with another researcher to explore the influence of pTA on expert culture as part of an NSF-funded research study (NSF award #1827826).

ECAST's distributed structure also promotes independence, continuity, and sustainability. However, shift in patronage can occur between legislative or executive regimes, or even during a single regime, due to changes in policy priorities. Our first federally sponsored project did not materialize until President Obama's second administration, even though civil servants from the U.S. Office of Technology Assessment and the Government Accountability Office expressed interest in our work much earlier. We also experienced a shift in our portfolio after the 2016 U.S. administration change when we pivoted to philanthropic and local government sources of funding and government-industry-nonprofit partner coalitions. The shift became an opportunity to support democratic decision-making in a much broader context rather than organizational dissolution, and was accomplished without compromising ECAST's principles or goals.

Establishing strong partnerships among experts, stakeholders, conveners, and project funders is a critical element of the process. As Polk (2015) highlights, even the generation of socially-robust, co-produced knowledge is not enough to ensure its uptake. The outputs from our pTA method proved most valuable for decision-making when the project had a direct connection to a policy decision and when there were strong "process champions" creating the space and legitimacy for this type of work in the relevant decision-making bodies (Torres, 2021).

While not currently formally measured as such, many of the ECAST pTA method's outcomes, such as the breadth of the ECAST portfolio, the establishment of new partnerships, and the identified organizational impacts align with established measurements of success such as feasibility, usability, and utility that are used to assess other process-based approaches (Platts, 1993; Platts and Gregory, 1990). In future pTA projects, we can apply these measures more systematically to compare successes across projects and assess whether we are becoming more successful over time.

Finally, in light of the COVID-19 pandemic, we have had to adapt our method to a virtual format. Examples of successful large-scale online deliberations exist, including the final round of France's Citizen Convention on Climate (Giraudet et al., 2021). The deliberations we hosted virtually allowed us to reach participants from a greater geographic range and engage with certain demographic groups that are harder to reach in a city setting. We ultimately felt, however, that the virtual deliberations were not good substitutes for in-person deliberations. Given the unique stressors and distractions of the pandemic-induced lockdowns, we feel the topics we explored in our virtual deliberations require further discussion during more normal times. Further, we found that virtual deliberations were still resource intensive as they still required facilitators and notetakers.

As we share our pTA method and lessons from our projects, we hope to return to the original vision for the network—operationalizing principles to support democratic decision-making. While we originally set out to help expand the voices and values providing science and technical advice to U.S. Congress, we found a need and demand for this work in multiple branches and levels of governance, and in different decision contexts. We plan to continue revising our method to better support democratic steering of science policy decisions.[7] Even so, we hope to build capacity to conduct pTAs beyond our network in the federal agencies, local governments, science museums, informal public venues, and beyond. Over time, these organizations could integrate deliberative practices into their organizations; perhaps no longer even needing an external actor like ECAST for routine rulemaking and decision support. The issues facing the global scientific community—from climate change to human genome editing to artificial intelligence—necessitate inclusion of a broad set of public values and voices to support democratic decision-making. We hope that this paper illustrates how an iterative, reflexive, collaborative, distributed, and innovation-focused approach can create sustained capacity to help meet this demand.

## CRediT authorship contribution statement

**Leah R. Kaplan:** Investigation, Project administration, Writing - original draft. **Mahmud Farooque:** Conceptualization, Methodology, Investigation, Writing - review & editing, Supervision, Funding acquisition. **Daniel Sarewitz:** Conceptualization, Writing - review & editing, Funding acquisition. **David Tomblin:** Conceptualization, Methodology, Investigation, Writing - review & editing, Supervision.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

[7] We see the reflexive and adaptable nature of our approach as one of its most valuable features. Rather than view the method as fixed, we consider it continually evolving. The three core phases of our approach (Problem Framing, ECAST Deliberations, and Results & Integration) distinguish it as an ECAST pTA deliberation, but the specific features of those phases may vary to meet the needs of the democratic decision-makers.


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## References


Arnstein, S.R., 1977. Technology assessment: opportunities and obstacles. IEEE. Trans. Syst. Man Cybern. 7, 571–582. https://doi.org/10.1109/TSMC.1977.4309782.

ASU, S., 2018. Discussion of Office of Planetary Defense Creation. ASU Barrett & O'Connor Washington Center, Washington, DC.

Barben, D., Fisher, E., Selin, C., Guston, D., 2008. Anticipatory governance of nanotechnology: foresight, engagement, and integration, in: Hackett, E.J., Amsterdamska, O. (Eds.), The Handbook of Science and Technology Studies. MIT Press, Cambridge, MA, pp. 979–1000.

Bellamy, R., Chilvers, J., Vaughan, N.E., 2016. Deliberative mapping of options for tackling climate change: citizens and specialists 'open up' appraisal of geoengineering. Pub. Underst. Sci. 25, 269–286. https://doi.org/10.1177/0963662514548628.

Bellamy, R., Chilvers, J., Vaughan, N.E., Lenton, T.M., 2013. Opening up' geoengineering appraisal: multi-criteria mapping of options for tackling climate change. Glob. Environ. Chang. 23, 926–937. https://doi.org/10.1016/j.gloenvcha.2013.07.011.

Bellamy, R., Lezaun, J., Palmer, J., 2017. Public perceptions of geoengineering research governance: an experimental deliberative approach. Glob. Environ. Chang. 45, 194–202. https://doi.org/10.1016/j.gloenvcha.2017.06.004.

Braun, V., Clarke, V., 2006. Using thematic analysis in psychology. Qual. Res. Psychol. 3, 77–101.

Cash, D.W., Clark, W.C., Alcock, F., Dickson, N.M., Eckley, N., Guston, D.H., Jäger, J., Mitchell, R.B., 2003. Knowledge systems for sustainable development. Proc. Natl. Acad. Sci. 100, 8086–8091.

Chilvers, J., 2008. Deliberating competence: theoretical and practitioner perspectives on effective participatory appraisal practice. Sci. Technol. Hum. Valu. 33, 421–451.

Chilvers, J., Kearnes, M., 2020. Remaking participation in science and democracy. Sci. Technol. Hum. Valu. 45, 347–380. https://doi.org/10.1177/0162243919850885.

Chilvers, J., Longhurst, N., 2016. Participation in transition (s): reconceiving public engagements in energy transitions as co-produced, emergent and diverse. J. Environ. Polic. Plan. 18, 585–607.

Christopherson, E.G., Scheufele, D.A., Smith, B., 2018. The civic science imperative. Stanf. Soc. Innov. Rev. 16, 46–52.

Danish Board of Technology, 2012. World Wide Views On Biodiversity. The Danish Board of Technology Foundation, Copenhagen.

Delborne, J., Schneider, J., Bal, R., Cozzens, S., Worthington, R., 2013. Policy pathways, policy networks, and citizen deliberation: disseminating the results of world wide views on global warming in the usa. Sci. Pub. Polic. 40, 378–392.

Dryzek, J.S., 2012. Foundations and Frontiers of Deliberative Governance. Oxford University Press.

Duncan, R., Robson-Williams, M., Edwards, S., 2020. A close examination of the role and needed expertise of brokers in bridging and building science policy boundaries in environmental decision making. Palgra. Commun. 6, 1–12. https://doi.org/10.1057/s41599-020-0448-x.

Durán, J.M., Pirtle, Z., 2020. Epistemic standards for participatory technology assessment: suggestions based upon well-ordered science. Sci. Eng. Ethic. 26, 1709–1741.
Dykema, J.A., Keith, D.W., Anderson, J.G., Weisenstein, D., 2014. Stratospheric controlled perturbation experiment: a small-scale experiment to improve understanding of the risks of solar geoengineering. Philos. Trans. R. Soc. Math. Phys. Eng. Sci. 372, 20140059.
Emery, S.B., Mulder, H.A., Frewer, L.J., 2015. Maximizing the policy impacts of public engagement: a european study. Sci. Technol. Hum. Valu. 40, 421–444.
Evans, R., Kotchetkova, I., 2009. Qualitative research and deliberative methods: promise or peril? Qual. Res. 9, 625–643.
Felt, U., Fochler, M., 2010. Machineries for making publics: inscribing and de-scribing publics in public engagement. Minerv. 48, 219–238.
Felt, U., Fouché, R., Miller, C.A., Smith-Doerr, L., 2017. The Handbook of Science and Technology Studies. MIT Press.
Fischer, F., 2000. Citizens, experts, and the environment: The politics of Local Knowledge. Duke University Press.
Fisher, E., 2019. Governing with ambivalence: the tentative origins of socio-technical integration. Res. Polic. 48, 1138–1149. https://doi.org/10.1016/j.respol.2019.01.010.
Fisher, E., 2005. Lessons learned from the ethical, legal and social implications program (elsi): planning societal implications research for the national nanotechnology program. Technol. Soc. 27, 321–328. https://doi.org/10.1016/j.techsoc.2005.04.006.
Fisher, E., Mahajan, R.L., 2006. Contradictory intent? us federal legislation on integrating societal concerns into nanotechnology research and development. Sci. Pub. Polic. 33, 5–16. https://doi.org/10.3152/147154306781779181.
Funtowicz, S., Ravetz, J., 1990. Post-normal science: a new science for new times. Sci. Eur. 266, 20–22.
Funtowicz, S., Strand, R., 2007. Models of science and policy. Biosaf. First Holist. Approach. Risk Uncertain. Genet. Eng. Genet. Modif. Org. 263–278.
Funtowicz, S.O., Ravetz, J.R., 1993a. Science for the post-normal age. Futur. 25, 739–755. https://doi.org/10.1016/0016-3287(93)90022-L.
Funtowicz, S.O., Ravetz, J.R., 1993b. The emergence of post-normal science. Science, Politics and Morality. Springer, pp. 85–123.
Gibbons, M., 1999. Science's new social contract with society. Nat. 402, C81–C84.
Giraudet, L.-.G., Apouey, B., Arab, H., Baeckelandt, S., Begout, P., Berghmans, N., Blanc, N., Boulin, J.-.Y., Buge, E., Courant, D., Dahan, A., F, A., 2021. Deliberating On Climate Action: Insights from the French Citizens' Convention for Climate (Working Papers No. hal-03119539). HAL.
Graves, Z., Cook-Deegan, R., 2019. Incorporating ethics into technology assessment. Issues Sci. Technol. 36, 26–29.
Guston, D.H., 2011. Anticipatory governance: a strategic vision for building reflexivity into emerging technologies. Resil. 2011 Ariz. State Univ. Tempe AZ 14 March 2011.
Guston, D.H., Sarewitz, D., 2002. Real-time technology assessment. Technol. Soc. 24, 93–109. https://doi.org/10.1016/S0160-791X(01)00047-1.
Herdman, R.C., Jensen, J.E., 1997. The ota story: the agency perspective. Technol. Forecast. Soc. Chang. 54, 131–143. https://doi.org/10.1016/S0040-1625(96)00167-9.
Jasanoff, S., 2003. Technologies of humility: citizen participation in governing science: reflections on the new production of knowledge. Minerv. Lond. 41, 223–244.
Jones, N.A., Ross, H., Lynam, T., Perez, P., Leitch, A., 2011. Mental models: an Interdisciplinary Synthesis of Theory and Methods. Ecol. Soc, p. 16.
Joss, S., Bellucci, S., 2002. Participatory Technology assessment: European perspectives. Center for the Study of Democracy.
Joss, S., Durant, J., 1995. In: Public Participation in Science: The Role of Consensus Conferences in Europe. NMSI Trading Ltd.
Kaplan, L., Nelson, J.P., Tomblin, D., Farooque, M., Bedsted, B., Sarewitz, Daniel, 2019. Cooling a warming planet? Pub. Form. Clim. Intervent. Resea..
Kerr, A., Cunningham-Burley, S., Tutton, R., 2007. Shifting subject positions: experts and lay people in public dialogue. Soc. Stud. Sci. 37, 385–411.
Kitcher, P., 2001. Science, truth, and Democracy. Oxford University Press.
Kolodny, L., Schoolov, K., 2019. Self-driving Cars Were Supposed to Be Here Already — Here's Why They Aren't and When They Should Arrive [WWW Document]. CNBC. URL. https://www.cnbc.com/2019/11/30/self-driving-cars-were-supposed-to-be-here-already-heres-whats-next.html (accessed 5.11.21).
Lehtonen, M., 2010. Deliberative decision-making on radioactive waste management in finland, france and the uk: influence of mixed forms of deliberation in the macro discursive context. J. Integr. Environ. Sci. 7, 175–196.
Lezaun, J., Marres, N., Tironi, M., 2017. Experiments in Participation, in: Felt, U., Fouché, R., Miller, C.A., Smith-Doerr, L. (Eds.), The Handbook of Science and Technology Studies. MIT Press, Cambridge, MA, pp. 195–221.
Lloyd, J., Tomblin, D., Farooque, M., 2018. Issue Advisory - Driverless Vehicles: What Priorities Should Be At The Top Of Our List?.
Lövbrand, E., Pielke Jr,, R., Beck, S., 2011. A democracy paradox in studies of science and technology. Sci. Technol. Hum. Valu. 36, 474–496.
Macnaghten, P., 2017. Focus groups as anticipatory methodology: a contribution from science and technology studies towards socially resilient governance. A New Era in Focus Group Research. Springer, pp. 343–363.
Macnaghten, P., Davies, S.R., Kearnes, M., 2019. Understanding public responses to emerging technologies: a narrative approach. J. Environ. Polic. Plan. 21, 504–518. https://doi.org/10.1080/1523908X.2015.1053110.
McCain, L., 2002. Informing technology policy decisions: the us human genome project's ethical, legal, and social implications programs as a critical case. Technol. Soc., Americ. Perspect. Sci. Technol. Polic. 24, 111–132. https://doi.org/10.1016/S0160-791X(01)00048-3.
NAPA, 2019. In: Science and Technology Policy Assessment: A Congressionally Directed Review. The National Academy of Public Administration.
NASEM, 2008. Public involvement usually leads to better environmental decision making; report offers guidance to federal agencies on public participation [www document]. Natl. Acad. Sci. Eng. Med. URL https://www8.nationalacademies.org/onpinews/newsitem.aspx?RecordID=12434 (accessed 5.11.21).
National Research Council, 2015. Climate intervention: Reflecting sunlight to Cool Earth. National Academies Press.
National Research Council, 2013. Nonresponse in Social Science surveys: A research Agenda. National Academies Press.
NOAA-SEC-OED-2015-2004408: Strengthening the Public's and/or K-12 Students' Environmental Literacy for Community Resilience to Extreme Weather Events and Environmental Changes [WWW Document], 2015. . Grants.gov. URL https://www.grants.gov/web/grants/view-opportunity.html?oppId=274854 (accessed 5.11.21).
Nowotny, Helga., Scott, Peter., Gibbons, M., 2001. *Re*-thinking science : knowledge and the public in an age of uncertainty. Polity.
NWTRB, 2016. In: Survey of National Programs for Managing High-Level Radioactive Waste and Spent Nuclear Fuel: Update. U.S. Nuclear Waste Technical Review Board report to Congress and the Secretary of Energy.
Pallett, H., 2015. Public participation organizations and open policy: a constitutional moment for british democracy? Sci. Commun. 37, 769–794.
Parkhill, K., Pidgeon, N., Corner, A., Vaughan, N., 2013. Deliberation and responsible innovation: a geoengineering case study. Respons. Innov. Manag. Respons. Emergen. Sci. Innov. Soc. 219–240.
PCSBI, 2016. Bioethics for every generation: deliberation and education in health, science, and technology.
Pielke Jr, R.A., 2007. The Honest broker: Making Sense of Science in Policy and Politics. Cambridge University Press.
Platts, K.W., 1993. A process approach to researching manufacturing strategy. Int. J. Oper. Prod. Manag. 13, 4–17. https://doi.org/10.1108/01443579310039533.
Platts, K.W., Gregory, M.J., 1990. Manufacturing audit in the process of strategy formulation. Int. J. Oper. Prod. Manag. 10, 5–26. https://doi.org/10.1108/EUM0000000001264.
Polk, M., 2015. Transdisciplinary co-production: Designing and Testing a Transdisciplinary Research Framework For Societal Problem solving. Futures, "Advanc. Transdisciplinar. 2004-2014" 65, 110–122. https://doi.org/10.1016/j.futures.2014.11.001.
Rask, Mikko., Worthington, Richard., Lammi, Minna., 2012. Citizen Participation in Global Environmental Governance. Earthscan, London.
Rourke, B., 2014. Developing Materials for Deliberative Forums. ERIC.
Rowe, G., Frewer, L.J., 2005. A typology of public engagement mechanisms. Sci. Technol. Hum. Valu. 30, 251–290.
Sarewitz, D., 2004. How science makes environmental controversies worse. Environ. Sci. Polic. 7, 385–403.
Schot, J., Rip, A., 1997. The past and future of constructive technology assessment. Technol. Forecast. Soc. Chang. 54, 251–268.
Schwarz, M., Thompson, M., 1990. Recognizing and analyzing the inchoate. divid. we stand redefining polit. Technol. Soc. Choic. 1–13.
Sclove, R., 2020. Forum [www document]. Issues Sci. Technol. URL. https://issues.org/forum36-2/(accessed 5.11.21).
Sclove, R., 2010. Reinventing Technology Assessment For the 21st century. Science and Technology Program. Woodrow Wilson International Center for Scholars (WWICS), Washington, DC.
Sclove, Richard., 1995. Democracy and technology, Conduct of Science Series. Guilford Press, New York.
Senge, P.M., 2006. The fifth discipline: the art and practice of the learning organization. Art and Practice of the Learning Organization. Doubleday/Currency, New York.
Smits, R., van Merkerk, R., Guston, D.H., Sarewitz, Daniel, 2010. The role of technology assessment in systemic innovation policy, in: Smits, R., Kuhlmann, S., Shapira, P. (Eds.), The Theory and Practice of Innovation Policy: An International Research Handbook. Edward Elgar Publishing, Cheltenham, UK, pp. 389–418.
Steitz, D., 2015. Innovative study supports asteroid initiative. Journey To Mars [WWW Document]. NASA. URL. http://www.nasa.gov/feature/innovative-study-supports-asteroid-initiative-journey-to-mars (accessed 5.11.21).
Stilgoe, J., Lock, S.J., Wilsdon, J., 2014. Why should we promote public engagement with science? Pub. Underst. Sci. 23, 4–15. https://doi.org/10.1177/0963662513518154.
Stilgoe, J., Owen, R., Macnaghten, P., 2013. Developing a framework for responsible innovation. Res. Polic. 42, 1568–1580. https://doi.org/10.1016/j.respol.2013.05.008.
Stirling, A., 2008. Opening up" and "closing down": power, participation, and pluralism in the social appraisal of. Technol. Sci. Technol. Hum. Valu. 33, 262–294. https://doi.org/10.1177/0162243907311265.
Stirling, A., Mayer, S., 2001. A novel approach to the appraisal of technological risk: a multicriteria mapping study of a genetically modified crop. Environ. Plan. C Gov. Polic. 19, 529–555. https://doi.org/10.1068/c8s.
Strauss, A.L., Corbin, J.M., 1990. Basics of Qualitative research: Grounded Theory Procedures and Techniques. Sage Publications, Newbury Park, Calif.
The Royal Society, 1985. The Public Understanding of Science. The Royal Society, London.
Tomblin, D., Pirtle, Z., Farooque, M., Sittenfeld, D., Mahoney, E., Worthington, R., Gano, G., Gates, M., Bennett, I., Kessler, J., Kaminski, A., Lloyd, J., Guston, D., 2017. Integrating public deliberation into engineering systems: participatory technology assessment of nasa's. Aster. Redir. Miss. Astropolit. 15, 141–166. https://doi.org/10.1080/14777622.2017.1340823.

Tomblin, D., Worthington, R., Gano, G., Farooque, M., Sittenfeld, D., Lloyd, J., 2015. Informing nasa's asteroid initiative - a citizens' forum: final results report. consortium for science. Polic. Outcom.
Torres, C.G., 2021. Technology, Public Participation, and the American Bureaucracy: Political and Administrative Dimensions of Participatory Technological Assessment in United States Federal Agencies [Unpublished doctoral dissertation].
Transparency and Open Government, 2009. Memorandum For the Heads of Executive Departments and Agencies (No. E9-1777). Federal Register, United States Government, 74 FR 4685.
Vig, N.J., 1992. Parliamentary technology assessment iin europe: comparative evolution. Impa. Assess. 10, 3–24. https://doi.org/10.1080/07349165.1992.9725818.
Wibeck, V., Hansson, A., Anshelm, J., 2015. Questioning the technological fix to climate change–Lay sense-making of geoengineering in Sweden. Energ. Res. Soc. Sci. 7, 23–30.
Williams, L.D.A., Woodson, T.S., 2019. Enhancing socio-technical governance: targeting inequality in innovation through inclusivity mainstreaming. Minerv. 57, 453–477. https://doi.org/10.1007/s11024-019-09375-4.
Worthington, R., Cavalier, D., Farooque, M., Gano, G., Geddes, H., Sander, S., Sittenfeld, D., Tomblin, D., 2012. Technology Assessment and Public participation: From TA to pTA. Expert and Citizen Assessment of Science and Technology Network, Washington, DC.
Wynne, B., 1996. May the sheep safely graze? A Reflexive View of the Expert-Lay Knowledge Divide 44–83.

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