INFORMING NASA'S ASTEROID INITIATIVE – A CITIZENS' FORUM

FINAL RESULTS REPORT

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ABOUT THE PROJECT

Cooperative Agreement/Grant Number: NNX14AF95A
Purpose/Project: Participatory Technology Assessment of NASA's Asteroid Initiative
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ABOUT ECAST

The Expert and Citizen Assessment of Science and Technology (ECAST) network is a collaboration among university, informal science education, and policy research partners to establish a participatory technology assessment capability in the United States. ECAST engages a diverse array of experts, stakeholders, and everyday citizens in assessing the responsible design and use of emerging developments in science and technology. Working with partners in governmental, industrial, academic, and non-governmental settings, ECAST conducts innovative participatory assessment activities on a range of scientific and technological issues, and shares the results with policymakers, the media, and the general public.

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DISCLAIMER

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Executive Summary

Informing NASA's Asteroid Initiative: A Citizen's Forum

The Project

This cooperative effort implemented by NASA and the Expert and Citizen Assessment of Science and Technology (ECAST) Network provided a citizen-focused, participatory technology assessment of NASA's Asteroid Initiative to increase public understanding of and engagement in the Initiative. The project had two main goals: 1) develop and apply a participatory technology assessment that elicited nuanced information from a diverse group of citizens whose insights would not otherwise be available to decision makers; and 2) through informed, structured feedback from citizens in multiple locations, provide public views of the Asteroid Initiative as input into NASA's decision-making process.

NASA's Asteroid Initiative, the focus of the citizen deliberations, has two central components. The first is the Asteroid Grand Challenge (AGC), a planetary defense effort that seeks to detect all asteroid threats to human populations and determine appropriate actions for dealing with or mitigating them. The second component, and the aspect most relevant to future human space exploration, is the Asteroid Redirect Mission (ARM). ARM would use an unmanned spacecraft to either capture an entire asteroid or retrieve a small boulder from a larger asteroid and put it into a stable orbit around the moon, at which point astronauts would rendezvous with the asteroid to study it. These efforts are part of NASA's broader goals to accelerate efforts to detect and mitigate the threat of potentially hazardous asteroids, and to enable the first human mission to an asteroid.

The Asteroid Initiative is taking place within a larger strategic shift at NASA about how to implement its exploration goals, including a crewed mission to Mars. The capability-driven framework (CDF) approach leverages and integrates NASA's activities in human exploration, space technology, and space science to advance the capabilities needed for future human and robotic explorations. In this sense, the Asteroid Initiative, through ARM, can be seen as contributing to the "Proving Ground" for the technologies that may one day enable a crewed journey to Mars, in addition to the more immediate objectives of detecting and mitigating asteroid threats. NASA focuses on the Proving Ground, which we connected to the CDF, as an evolving set of missions that prepare for and demonstrate our ability to safely live and work away from Earth for extended periods before attempting a mission to Mars.

Participatory technology assessment involves engaging a group of lay citizens who are representative of the general population but who—unlike political, academic, and industry stakeholders—are generally underrepresented in technology-related policymaking. This participatory technology assessment of NASA's Asteroid Initiative allowed citizens with various backgrounds, values, and knowledge to express important views on this topic that credentialed scientists and engineers, stakeholders, and policymakers might otherwise overlook or undervalue. The project was strongly aligned with the Obama Administration's directive to federal departments and agencies to promote broad public participation in their activities and to be responsive to citizen concerns.

The Process

ECAST developed, implemented, analyzed, and assessed two on-site, face-to-face forums in November 2014, one in Phoenix, AZ and the other in Boston, MA, and one online citizen forum for collecting informed public views about NASA's Asteroid Initiative (Section 2.1). After a kickoff meeting with NASA, ECAST designed and tested deliberation materials, including background information packets, videos, a planetarium program, and value-mapping exercises (2.4). ECAST also selected and trained the facilitators for the deliberations, and designed pre- and post-forum surveys to determine participants' attitudes toward and knowledge of asteroid and space exploration (2.6).

ECAST undertook the recruitment of the lay citizen participants, achieving a distribution that aligned with the demographic characteristics of their respective states. Ninety-eight citizens participated in the Phoenix forum and 88 participated in the Boston forum (2.6). Organizers limited the number of participants active in space exploration (advocates, launch attendees, aerospace professionals, etc.) because their views are already known by NASA and they would be likely to dominate discussions (2.6).

With participants broken into table groups of 6-8 people, the forums consisted of four discussion sessions: 1) *Planetary Defense 1: Asteroid Detection*; 2) *Planetary Defense 2: Asteroid Mitigation*; 3) *Asteroid Redirect Mission*; and 4) *Journey to Mars*. Trained facilitators at each table ensured a substantive and focused discussion of the issues, and NASA experts were on hand to answer technical questions (2.3). ECAST also organized an open online deliberation to discuss these topics, but due to limited participation and insufficient data, the results of the online component are not analyzed in this report (2.5).

Planetary Defense 1: Asteroid Detection (3.0)

> In this session, participants were asked to consider three policy options regarding asteroid detection: 1) maintain current detection capabilities; 2) institute an extended ground-based system; or 3) implement space-based asteroid observation. The session had six components and ran for 90 minutes. After discussion, participant groups were asked to recommend which of the three options, if any, they would enact; what they found to be the most compelling reasons for the option they chose; and what entities or groups should be responsible for leading asteroid detection (which were referred to as "Guardians").

Planetary Defense 2: Asteroid Mitigation (4.0)

> In the second session, participants considered four primary asteroid mitigation options and the tradeoffs associated with each: 1) civil defense; 2) slow-push orbit change (also called a gravity tractor); 3) kinetic impactors; and 4) nuclear detonation or other blast deflection. (They could also consider doing nothing.) The session had five components and lasted 90 minutes. The groups discussed potential impact scenarios (e.g., a "planet-killing" asteroid with a 10% chance of hitting the earth in 20 years) and accompanying hypothetical changes to these scenarios (e.g., a 50% chance of hitting the earth rather than 10%, or a projected impact in 50-100 years rather than 20), and selected their preferred mitigation method based on the scenario and contingent factors. Once again, participants were asked which institutional Guardians they preferred to lead mitigation efforts for each scenario.

Asteroid Redirect Mission (5.0)

> This session solicited group and individual preferences about ARM, including two different options for performing the mission: Option A was to capture an entire asteroid with an inflatable bag system; Option B entailed retrieving a smaller boulder from the surface of a large asteroid. A short video outlined the tradeoffs between the two mission scenarios and introduced the Proving Ground strategy, so that participants could address ARM in the context of the future of human spaceflight. Participants discussed the ARM options and provided group recommendations, discussing potential mission goals as well as different acceptable risks that may occur.

Journey to Mars (6.0)

> Participants in the final session deliberated on mission scenario preferences for a planned crewed Mars mission, contrasting three different mission scenarios: 1) a strategy to send a crew to Mars orbit

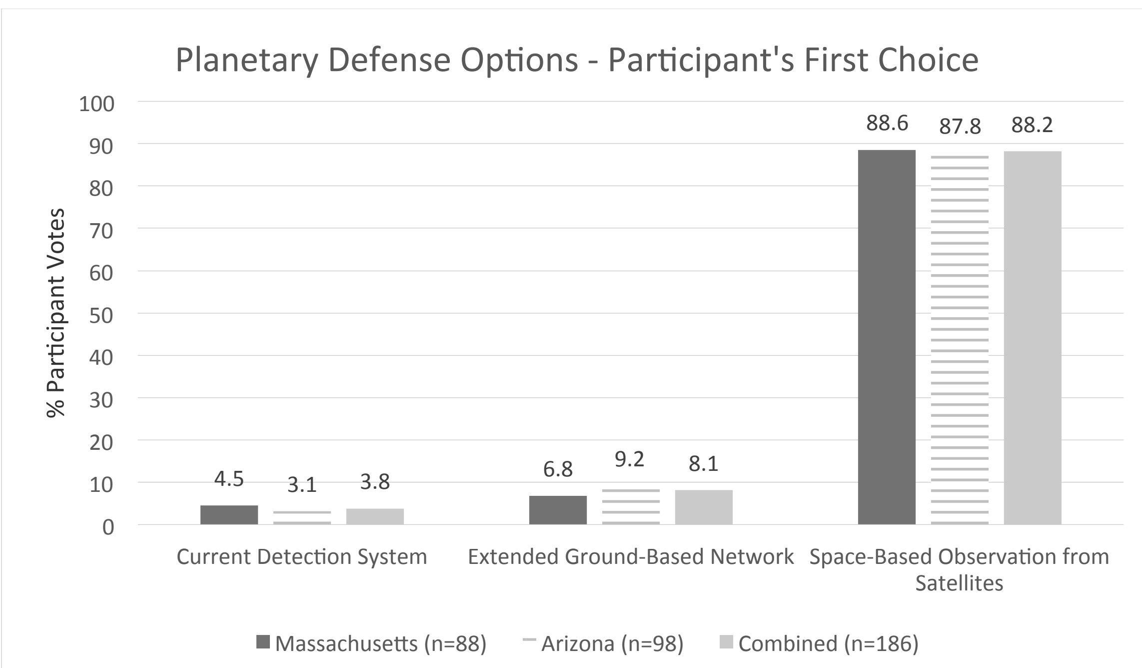
and potentially the Mars moons; 2) a "Viking" strategy, with a 30-day crewed mission to the Martian surface; and 3) a "Pioneer" permanent settlement strategy. Each option was described as progressively requiring more time, increased costs, and greater risks, and citizens were asked to consider which option to pursue after NASA's Proving Ground missions were complete. Individuals recommended one of these exploration strategies and considered whether the Proving Ground strategy, which represents the incremental capability-driven framework, was an acceptable approach to achieving the selected option.

The Results

According to the post-forum survey, participants were highly satisfied with their experience at both sites. Pre- and post-forum surveys indicated that participants greatly increased their interest and knowledge in NASA's Asteroid Initiative and plans for space exploration (Section 2.6). The main findings from each of the on-site forum sessions are highlighted below.

Planetary Defense 1: Detection (3.3)

By a wide majority, participants at both sites selected to implement space-based observation of asteroids (option 3). An international partnership in which the United States and NASA would play a critical role was preferred to other options as the appropriate Guardian for planetary defense, with the most frequently cited rationale for this choice being that asteroid detection is a global issue and therefore a global responsibility.

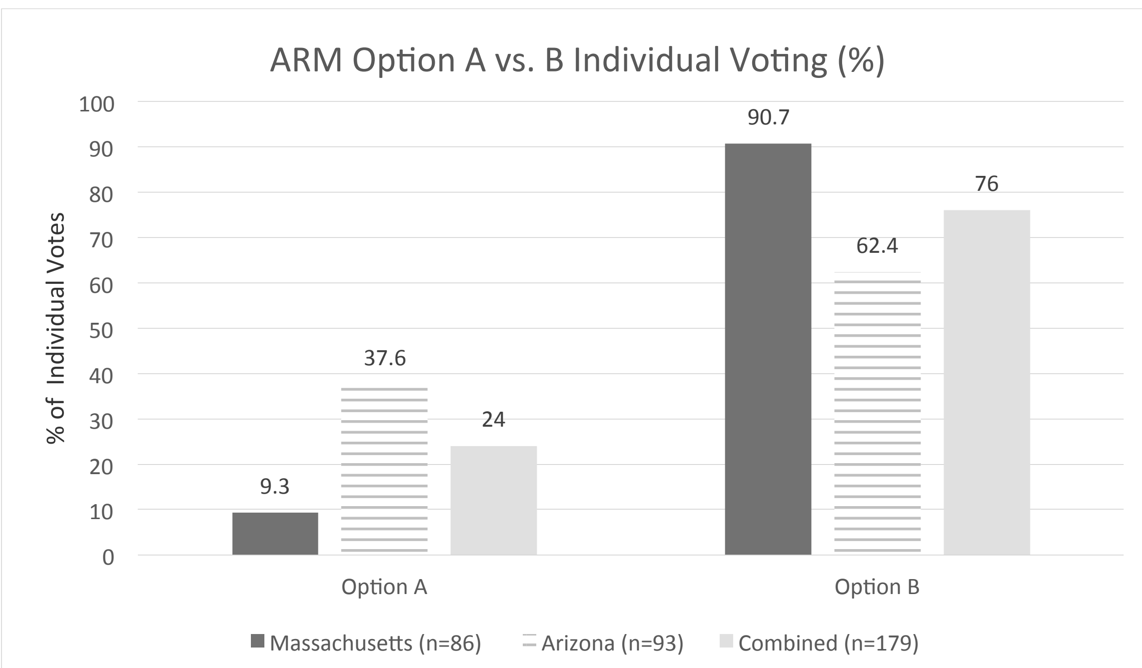


Planetary Defense 2: Mitigation (4.3)

While caution is required in combining score results across multiple scenarios (participants assessed 10 different scenarios), the planetary defense strategy most commonly chosen overall was nuclear detonation, followed closely by kinetic impactor and civil defense. Thus kinetic impactors were a fairly popular option, often chose by participants because they viewed it as a safer option than nuclear detonation. Despite being the most popular option overall, many citizens struggled with the nuclear detonation choice on ethical and political grounds, and were reluctant to choose this strategy unless confronted with a high probability of a continental-scale to planet-killer impact. However, not everyone fit this pattern: some participants were confident that nuclear weapons would be the most successful in all scenarios, whereas others refused to choose the nuclear option for even a planet killer scenario on ethical and political grounds. Civil defense was generally popular, likely because it was not deemed to be an exclusive choice. The gravity tractor had its highest support in long timeframe scenarios (20 years out), which would make sense due to the long lead times required for the tractor to work (4.3.1). The most popular Guardian shifted slightly relative to the detection session. Instead of a preference for a U.S.-led international collaboration, participants most frequently selected an international consortium that included NASA. Interestingly, preferred governance strategies were influenced with additional information—in this case, the asteroid impact scenarios (4.3.2).

Asteroid Redirect Mission (5.3)

After effectively incorporating scientific and technical details into their discussions and option selection considerations, participants at the two on-site forums selected ARM Option B (retrieving a boulder from a larger asteroid) over Option A (capturing an entire asteroid) by a wide margin. Option B group rationales included better control over selecting an appropriate asteroid, more obvious economic benefits, a more likely application to planetary defense, and more near-term benefits; according to participants, Option B also builds on proven technology and fits better with the proving ground strategy. Groups that preferred Option A believed that the approach had multiple uses, provided economic benefits, and posed fewer risks than Option B (5.3.1). On average, both sites chose the same top goals of the ARM program: "Advancing science," "Advancing planetary defense," and "Advancing technology needed for human spaceflight" (5.3.2).

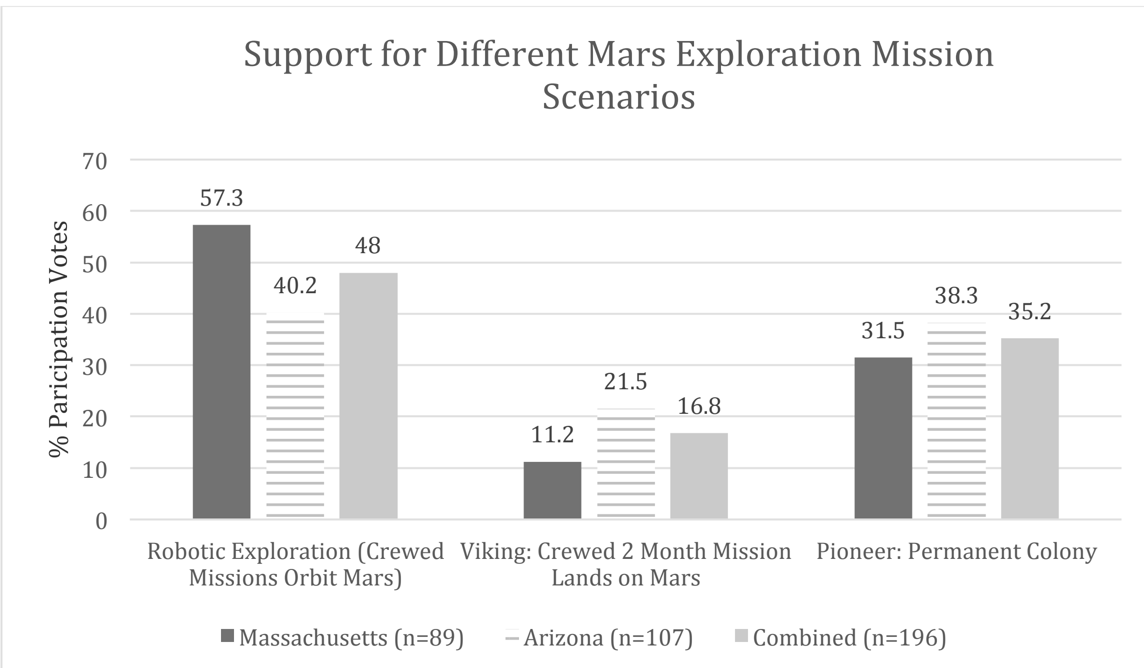


Journey to Mars (6.3)

Some citizens wanted to combine the three scenarios for Mars exploration, but they still voted on which goal they wanted to see as NASA's priority following the Proving Ground strategy. On average, participants at both sites favored sending astronauts to orbit the Red Planet, along with robotic exploration and possible Mars moon missions, over the Viking (crewed mission to land on Mars) and Pioneer (permanent settlement) scenarios. This may imply that people prioritized accomplishing a

Mars mission sooner, even without landing, as opposed to waiting longer to achieve more ambitious goals. Pioneer (permanent settlement) was rated more highly than Viking (short-duration crewed mission), with some data suggesting a preference to "go big or go home." Although the crewed orbit and robotic mission scenario was the most popular, there was still a strong preference among participants to actually land people on Mars, as the Viking and Pioneer scenarios together accounted for 52% of the public's preferred mission type overall. Nearly half favored the crew in orbit with robotic mission scenario because of cost and safety concerns for landing on Mars and a desire to have a human presence around Mars in a shorter time frame. Slightly more than half preferred a human mission to the planet's surface as outlined in the Viking and Pioneer scenarios; they cited as rationales maintaining public interest, becoming a "two-planet" species, and advancing science and technology.

In this session participants also discussed NASA's Proving Ground strategy, which represents an incremental approach to planning future missions and is conceptually related to the capability-driven framework. A majority of people at both sites supported moving forward with the Proving Ground approach, which suggests that an informed public may endorse an incremental planning approach to advance deep space exploration as opposed to the traditional destination-oriented mission model.



The Report

This report is organized into three main sections. *Part I: Introduction and Overview* describes the goals of the project and the participatory technology assessment approach, and details the design of the forum, including participant characteristics and their motivations. *Part II: Themes, Results, and Analysis* addresses the outcomes of each of the four thematic sessions, with detailed discussion of the results and observations made by researchers present at the deliberations. *Part III: Reflections and Refinements* offers an assessment of how the project could be improved and outlines opportunities for future research. Detailed statistical data are reported in the appendices.

Part I – Introduction and Overview

1.0 Introduction

This report presents and analyzes the results from “A Participatory Technology Assessment of NASA’s Asteroid Initiative,” a cooperative agreement (Grant Number NNX14AF95A) executed between NASA and the Expert and Citizen Assessment of Science and Technology (ECAST) network, led by Arizona State University, Museum of Science Boston, and SciStarter.com.

Under the agreement, NASA was responsible for:

1. Providing expertise and background materials on the NASA Asteroid Initiative;
2. Collaborating with ECAST on the design and testing of the materials and processes for participatory technology assessments of the NASA Asteroid Initiative; and
3. Providing expert input at the citizen deliberations in response to public questions.

In turn, ECAST was responsible for:

1. Collaborating with NASA, and designing and testing the materials and process for participatory technology assessments of the NASA Asteroid Initiative;
2. Hosting two on-site deliberation forums (one in Boston and one in Phoenix) with approximately 100 non-expert citizens to elicit their informed feedback on the NASA Asteroid Initiative;
3. Hosting an open online deliberation coordinated with the on-site deliberations to extend the reach of the conversation; and
4. Collecting the data from these three deliberations to assess the process and outcomes, and providing these to NASA in a report to be used as input to early-stage planning of the Asteroid initiative and other engagement activities.

1.1 Objectives

The objectives of this report are to (1) present the results of the face-to-face and online citizen deliberations; (2) analyze the results, including their validity; (3) assess what went well and what could be improved; and (4) assess the utility of the deliberative model used in the project for decision support more generally.

In presenting the voting results generated by the participants’ discussions, we also address the reasoning processes that participants used in arriving at their individual and group perspectives. In addition, we assess the credibility of the results by considering such questions as:

1. Were the citizens’ views as expressed by their individual and group votes affected by the demographic characteristics of the participants?
2. Did the framing of the deliberation and of specific issues and questions steer participants in particular directions?
3. How did citizens build their arguments?
4. How much influence did expert input during the deliberations influence participant voting patterns?
5. What factors explain disagreements among participants about technical and policy decisions?
6. How much did participants learn from the process?
7. How well did the participants understand the background information provided in advance and in information videos screened at the event?
8. Did a few people dominate the discussions among participants, or was there genuine give-and-take that yielded better-informed and more refined views?

1.2 Organization

The report is organized into three parts that contain the *Introduction and Overview*; *Themes, Results, and Analysis*; and *Reflections and Refinements*. Detailed statistical data are reported in the appendices. The next section addresses the rationale, background context, and design of the forum, including characteristics of the participants and their motivations. The bulk of the report is comprised of participant voting and rationales generated during the deliberations, the pre- and post-forum surveys given to participants before and after each deliberation, and observations made by researchers who sat at selected tables in both Boston and Phoenix for the entire day. An online forum was also conducted and is discussed in Section 2. **Those interested in exploring the results of the report can move to Sections 3.0-6.0 after a perusal of the initial background of the report.** A separate, significantly condensed version of this report also exists that focuses on high-level results; that version is available at the project website at: http://cspo.org/research/a-participatory-technology-assessment-of-nasas-asteroid-initiative/.

1.3 Data Sources and Approach

We derived data for the report from four sources:

1. Applicant demographic data;
2. Participant voting results as well as group and individual written rationales collected during the deliberations;
3. Table observations during the deliberations; and
4. Pre- and post-forum surveys given to participants.

There were four basic analytical tasks undertaken by the ECAST research team:

1. The quantitative voting results were tabulated for each site to discern the participant preferences that emerged during each thematic session. We analyzed these results for site differences and also calculated overall averages for both sites combined. Specific statistical analyses used to analyze results are presented in Appendix H.
2. We analyzed survey data in a similar manner. Overall trends are presented, unless relatively large differences among participant responses by site for a specific survey category were evident. Specific statistical analyses used to analyze results are presented in Appendix H.
3. Group and individual qualitative responses collected as a part of session voting were grouped thematically using an open coding approach. For this operation, a single coder reviewed responses and developed thematic schemes to describe patterns in the response rationales in each dialog section. Scope notes describing each theme are included in tables and appendices. Because a single coder developed the schema, statistical tests for inter-coder reliability involving multiple analysts could not be performed to measure or calibrate coding consistency.
4. We also conducted table observations at four tables in Phoenix and four tables in Boston. These have been used as a record of what participants actually said, as well as the nature of their conversations and interpersonal interactions, in order to tease out insights that were not evident from the quantitative and qualitative data. More information on the table observation method can be found in Appendix H: Table Observation Protocol.

Altogether, the data listed above are quite considerable, with many spreadsheets full of written responses as well as written transcript analyses. However, assessing all of this data within the time allotted for completion of this project exceeds the scope of this report. The analyses contained in the discussion sessions for each deliberation section explores the research questions above, teasing them out when the data enabled it. We utilized a variety of analytical approaches to show insights when they were achievable. Part of the goal for the report is to demonstrate the richness of data that can be attained through participatory technology assessment approaches, both in terms of exploring public views and furthering academic understanding. Even with this limited analysis, the forum does provide insights relevant to the Asteroid Initiative that show the value of this approach in supporting decisions as well as designing better engagement.

Caution should be exercised in extrapolating the results from the 186 citizens that attended the forums in two different geographic locations. These types of forums are not oriented to provide a statistically accurate reflection of the views of the American public. Rather, the goal of the exercise was to provide NASA with a diverse set of views and accompanying rationales that go beyond what can be produced through surveys, opinion polls, and focus groups. It may be the case that some of the results from the forum align closely with the views held by the broader public, but that coincidence should be assessed with further research. What can be said here is that there is a broad set of insights provided by what seems to be diverse and not otherwise engaged or vested members of the public. The values and preferences they express represent some citizen preferences, which are likely worth considering on their own even if they are not fully representative of public views at large.

Opinions and analysis in this report reflect ECAST and the authors' opinions, and do not necessarily reflect the opinions of the National Aeronautics and Space Administration or the United States Government. ECAST also takes responsibility for the content of the background material here, which was created for deliberation and research purposes and not for establishing policy or technical briefings.

2.0 About Informing NASA's Asteroid Initiative – A Citizen Forum

In this section we provide background and context for the project, an overview of the forum design, the demographic characteristics of the participants, and their views about their experiences. This information about the organization of the day and analysis of the quality of participants' experiences is critical in framing the forum results and, in particular, the extent to which these results reflect a balanced, open, informed, and respectful conversation among ordinary citizens.

2.1 Background and Context

NASA's Asteroid Initiative encompasses two parts:

- The Asteroid Grand Challenge (AGC), which is dedicated to finding all asteroid threats to the human population and determining what to do about them.
- The Asteroid Redirect Mission (ARM), which plans to capture an asteroid, place it in orbit around the moon, and then send astronauts to dock with it.

In July 2013, NASA released a Request for Information (RFI) related to the Asteroid Initiative, including a request for data on Partnership and Engagement. The Expert and Citizen Assessment of Science and Technology (ECAST) network responded to that RFI and recommended that NASA engage citizens in deliberative and participatory forums like World Wide Views (WWViews).[1] Also known as participatory technology assessment (pTA), such an effort would consider the potential benefits, tradeoffs, and long-term consequences of proposed policies or research directions that NASA is considering. By using citizen forums to inform decision makers about key principles and issues that need attention, the response argued, new perspectives will be brought forward that can help NASA better plan and implement missions.

NASA evaluated 402 of the submitted RFI responses for relevance, impact, maturity, and affordability and selected 96 of the most promising ideas for presentation at the Asteroid Initiative Ideas Synthesis Workshop. ECAST was among the 12 selected in the area of Partnership and Engagement. Presenting on behalf of ECAST, David H. Guston of Arizona State University offered examples and experiences from its distributed institutional model for bringing academic research, informal science education centers, citizen science programs, and non-partisan policy think tanks to conduct multi-site, large-scale deliberative citizen forums to inform policy and decision-making. He offered four principle ideas for NASA to consider as it sought to broaden participation in the Asteroid Initiative:

1. Increase public understanding of and engagement in Asteroid Initiative policy matters
    a. Transition to public engagement models
    b. Engage scientists, NASA personnel, and the public
2. Solicit informed, structured feedback from citizens in multiple geographic regions
    a. Multi-site structured deliberations
    b. Based on NASA expert-generated contents
3. Have continued feedback for future outreach approaches
    a. Outcomes research on public participation methods
    b. Dissemination of best practices

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[1] See http://wwviews.org/. See also ECAST's and other researchers' assessments of World Wide Views on Biodiversity: Worthington, R., D. Cavalier, M. Farooque, G. Gano, H. Geddes, S. Sander, D. Sittenfeld, and D. Tomblin (2012). *Technology Assessment and Public Participation: From TA to pTA* (Washington, DC: ECAST); Rask, M., R. Worthington, and M. Lammi, eds. (2011). *Citizen Participation in Global Environmental Governance.* (New York: Earthscan); Rask, R. and R. Worthington, eds. (2015). *Governing Biodiversity through Democratic Deliberation.* (New York: Routledge).

4. Provide onramp for public to engage in related, ongoing activities
    a. Engagement modules for science centers
    b. Connect citizen science efforts with decision-making

The Ideas Synthesis Workshop Report, released in January of 2014, embraced two of these principles and recommended that NASA, under its Asteroid Grand Challenge mission:

- Consider forums for engaging the public in two-way policy conversations;
- Build momentum through the use of smaller demos that can culminate in larger demos to leverage the shared progress; and
- Explore conversations about risk and learn from the natural disaster response community.

Following from these recommendations, in February of 2014, ECAST was invited to submit a proposal for a cooperative agreement with NASA to support a citizen-focused, participatory technology assessment of NASA's Asteroid Initiative. This pTA would further the academic understanding of these approaches and provide some public views of the Initiative as an input for Agency officials to consider in early planning efforts.

Responding to the request, in March of 2014, ECAST, represented by David Guston (PI), Mahmud Farooque (Co-PI), and Ira Bennett (Co-PI) of Arizona State University; David Sittenfeld (Co-PI), David Rabkin, and Larry Bell of Museum of Science Boston; Darlene Cavalier (Co-PI) of SciStarter.com; Rick Worthington of Pomona College; David Tomblin of University of Maryland; and Gretchen Gano of University of Massachusetts, Amherst, submitted a project proposal. It had three primary objectives:

1. Design, test, implement, analyze, and assess two on-site face-to-face and one online citizen forums for collecting informed public views on NASA's Asteroid Initiative;
2. Provide public views as an input to shape the Initiative's direction and further public engagement activities; and
3. Serve as a potential pilot for participatory technology assessment of NASA's future science and technology initiatives.

Table 2.1 Project Timeline

Apr '14	May '14	Jun '14	Jul '14	Aug '14	Sep '14	Oct '14	Nov '14	Dec '14	Jan '15	Feb '15	Mar '15	Apr '15*	May '15*	Jun '15*
Project Planning														
		Theme Development												
				Forum Design										
				Content Development										
					Recruitment									
							In Person and Online Forums							
							Interim Report				Final Report			

The project began on April 1, 2014 and continued until June 30, 2015 with the following milestones:

1. April – July, 2014: Planning and Design
    a. May 6-7: NASA-ECAST Project planning conversation, Washington, DC.
    b. June 13: Theme and questions for NASA review
    c. July 21: Theme finalized and forum schedule change*
2. August – October, 2014: Content Development and Participant Recruitment
    a. Aug. 12-13: NASA-ECAST Content development conversation, Boston, MA.
    b. Aug. 28: Press release and begin recruitment drive and online awareness
    c. Oct. 16: Deliberation content finalized
    d. Oct. 30: Video and Planetarium content finalized
3. November, 2014 – March 2015: Informing NASA's Asteroid Initiative – A Citizens' Forum
    a. Nov. 8: In-Person Citizen Forum in Phoenix, AZ
    b. Nov. 15: In-Person Citizen Forum in Boston, MA
    c. Nov. 8-23: Online Citizen Forum: Moderated Discussions

    d. Feb. 11-March 11: Online Citizen Forum: Amplifications
4. December, 2014 – June, 2015: Evaluation and Assessment
    a. Dec. 1: Interim Report on Asteroid Recovery Mission Downselect
    b. Dec. 10: Interim Report Supplement
    c. Mar. 19-20: Draft final results report presentation, Washington, DC
    d. May 15: Final results report for NASA review
    e. August 30: Final report released

2.2 Forum Design

The basic rationale for deliberative processes such as WWViews is that they provide an opportunity to see what lay citizens think in a situation where they have had the opportunity to learn about key facts and to discuss them with their citizen-peers. "Lay citizens" in these processes refer to publics who fund technology development (through taxes and consumer purchases), and who live with its positive and negative consequences, but are not otherwise formally engaged (through advocacy or expertise) in the subject technology's policy and decision-making processes. It is not a survey. It is not a poll. It is not a public hearing. It is a process for exploring the views and values lay publics have when they engage with complex socio-technical issues.[2]

Table 2.2 Strategies for Designing Asteroid Initiative Citizen Forums in Phoenix and Boston

Objective	Approach
Diverse Representation	• Citizens were recruited with the idea of selecting about 100 participants to be representative of the diversity of the population in the host state. • Higher priority placed on citizens not working or directly involved with NASA or space advocacy.
Making Informed Citizens	• A few days before the forums, participants were provided with background information on the themes and topics for discussion regarding asteroids and NASA's initiatives. • On forum day, participants experienced an original, immersive planetarium show about asteroids. • Prior to each thematic session on forum day, participants watched a 6-8 minute video reiterating the background information; deliberation materials also contained information pertaining to each session's issues.
Deliberative Learning and Engagement	• Participants were divided into small groups of 6-8 and assigned a table for the day. • Trained facilitators at each table ensured that each participant had an equal chance to register their views in small group discussion. • During group discussions, participants asked clarifying questions to NASA subject-matter experts and answers were tabulated and posted for the benefit of all participants at all tables.
Usable Outcomes	• Participants provided basic demographic information and answered questions about knowledge, activism, and political ideology. • Participants completed pre- and post-forum surveys recording their opinions about expectations, knowledge, and learning. • The themes, scenarios, strategies, and options in the learning materials and the specific questions discussed at each session were developed based on direct input from NASA program managers and decision makers. • Participants were given opportunities to register both group and individual responses to questions, and to record them in anonymous ballots.
Assessments	• Participant demographics and response data, views on group plans and individual opinion were tabulated, compared, analyzed, evaluated and assessed.

[2] Work on public value theory (Bozeman, B. 2007. *Public Values and Public Interest: Counterbalancing Economic Individualism.* Washington, DC: Georgetown University Press) has informed the practice of public value mapping (PVM), an analytical and decision support method for assessing how research and development programs address broadly accepted societal outcomes (Bozeman, B., and D. Sarewitz. 2011. "Public Value Mapping and Science Policy Evaluation." *Minerva*. 49 (1): 1-23). Participatory technology assessment in general and World Wide Views in particular are means for extracting public values through direct participation and engagement.

The forum design aims to produce such exploration by assuring diverse representation, providing unbiased information, and promoting respectful and open conversation about the issues. The objective is to produce results that can help decision makers and others not just to see opinions expressed in response to a question, but the views that people embrace after giving the issue serious consideration, as well as the nature of how they deliberate on it. The main design approaches for developing the deliberative citizen forums, developed in consultation with NASA, are depicted in Table 2.2.

2.3 Forum Content and Organization

The two primary objectives of the forum were to further the academic understanding of pTA approaches and to provide some public views as an input for Agency officials to consider in early planning efforts. These goals required close cooperation between ECAST and NASA project team members. NASA experts expressed interest in engaging participants in informed, respectful conversations about the Asteroid Initiative, which includes the Asteroid Grand Challenge and the Asteroid Redirect Mission noted above. These initiatives required providing new approaches and insights surrounding two primary focus areas: **planetary defense**, which comprised both detection of near-Earth objects (NEOs) and potential mitigation actions; and **deep space exploration,** which covered the Asteroid Redirect Mission (ARM) and a broader discussion of potential pathways and mission planning strategies for a journey to Mars.

In each area of interest to NASA, the first task was to identify the discussion questions for the deliberations, and then to develop materials that would both inform and engage the selected participants. To identify the questions, the ECAST content development team engaged with relevant NASA program managers through phone and online correspondence and through two carefully facilitated physical meetings in Washington and Boston. After a series of exchanges and consultations, ECAST and NASA partners decided together on a forum agenda centered on four research themes.

Table 2.3 Phoenix and Boston Citizen Forum Agenda

Time	***Activity***
8:00 – 9:00 AM	*Participant Check-in*
9:00 – 9:15 AM	*Welcome from ECAST and NASA*
9:15 – 9:45 AM	*Planetarium Introduction*
9:45 – 10:15 AM	*Snacks and Coffee*
10:15 – 11:45 AM	*Planetary Defense 1: Detection*
11:45 – 1:15 PM	*Planetary Defense 2: Mitigation*
1:15 – 2:15 PM	*Lunch*
2:15 – 3:15 PM	*Asteroid Recovery Mission A vs. B*
3:15 – 4:15 PM	*Human Exploration/Proving Ground*
4:15 – 4:45 PM	*Results from Deliberation, Post-Survey and Concluding Remarks*

This agenda included a morning session focused on planetary defense, with specific sessions on detection of NEOs and potential mitigation strategies. The afternoon session addressed deep space exploration, first engaging participants to consider and recommend one of two potential options for performing the ARM mission, known as Options A and B, and then discussing strategies for future exploration of Mars (Table 2.3).

Beyond these topical questions, though, lay the larger issue of the type of information that NASA experts hoped to elicit from the participants. **NASA experts expressed particular interest in learning about the kinds and quality of *values and perspectives* that everyday people bring to these kinds of decisions. There was also a wish, to be sure, to capture quantitative data that could be aggregated and statistically analyzed, but the importance of also identifying different priorities and societal norms underlying the technical and policy decisions was also evident.** NASA partners wanted to know not only whether participants thought an international collaboration should help shape and implement planetary defense efforts, for example, but also the role of social values and personal experience in influencing these policy preferences.

Therefore, the deliberation questions needed to produce both qualitative and quantitative responses that were well informed with regard to technical background, but connected to broader societal priorities and values. This presented a formidable challenge, because one of the project design objectives emphasized the importance of consulting participants who were not already engaged in thinking about space issues (to paraphrase the words of one program officer, a primary desire was to “hear from people we’re not hearing from already”). The technical details and complex policy aspects of the four topic areas, along with the charge to consider interconnected questions between the ARM and potential Mars mission scenarios, required the development of engaging and robust background information and creative augmentation of the World Wide Views forum design.

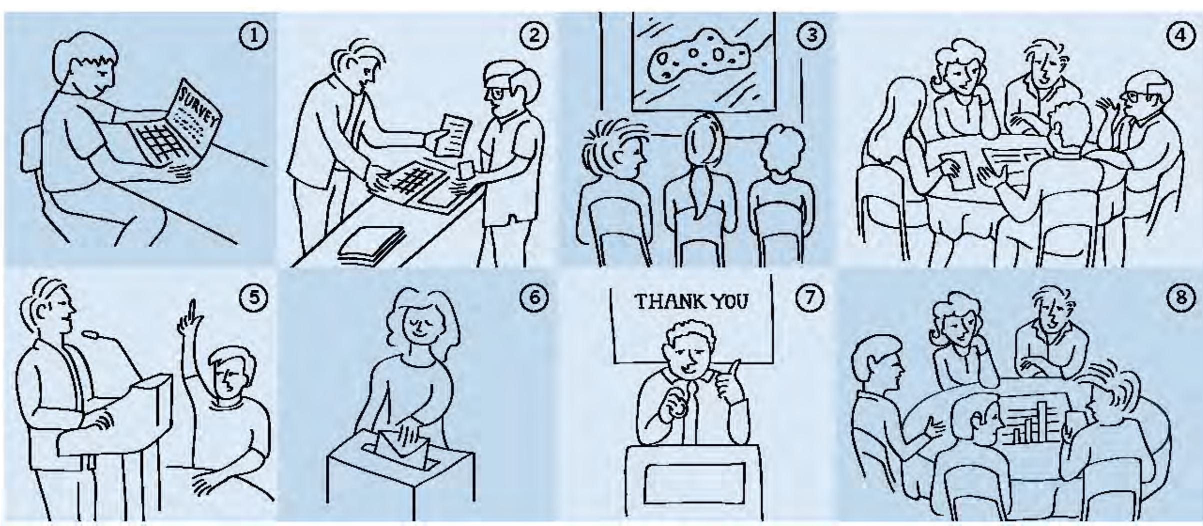

Figure 2.3.1 The Citizen Forum Process: *The forum process began with (1) recruiting, surveying, and briefing participants. On the day of the forum, participants (2) checked in and watched a planetarium show. Four discussion sessions followed, each consisting of (3) a video introduction to the topic, (4) group discussion, (5) expert Q&A, and (6) voting. The morning planetary defense sessions were 90 minutes apiece and the afternoon space exploration sessions were one hour each. At the end of the day, participants (7) were thanked and filled out a post-forum survey. Finally, the forum was (8) assessed and analyzed by organizers.*

Thematic sessions in the World Wide Views format contain three essential components: video, discussion, and individual voting on multiple-choice questions. In order to ensure a deeper level of learning for “Informing NASA’s Asteroid Initiative,” it was necessary not only to facilitate discussion among citizen peers, but also to provide the opportunity to obtain technical answers directly from NASA experts during these discussions. Hence the discussion period in each deliberation session included a twenty-minute window when participants could pose questions to NASA experts through a web interface. These question and the answers were displayed on the main projection screen so all participants could benefit and incorporate them in their group discussions.

Similarly, to ensure a deeper level of engagement, it was necessary to introduce group exercises in developing collective positions or recommendations in addition to individual voting. As an example of an engaging group exercise, at the content development meeting in Boston, ECAST partners presented a concept for a stakeholder value-mapping exercise using identity profile cards, which would help participants consider the kinds of priorities and perspectives influencing the policy options under consideration. NASA partners participated in an example from a prior National Science Foundation project on sea level rise adaptation, and saw value in incorporating a similar stakeholder value-mapping effort on planetary defense. A value-mapping exercise was thus included in the first session of the day (on asteroid detection), so that varying perspectives coming from different stakeholders (which included entities such as NASA, private industry, international partners, and the B612 Foundation) would resonate throughout the day’s conversations, and be a resource for the participants in considering strategies for the four deliberation areas.

Figure 2.3.2 Detection deliberation

2.4 Background Information, Videos, and Multimedia

The background information presented in Appendix G was developed in response to the questions for deliberation. The strategy was to provide participants with scientific and policy information that would inform the specific questions they would be considering. After presenting and co-developing basic narrative points at the planning meeting in Boston, content developers from the Museum of Science created content outlines that were reviewed by NASA program managers and directors.

Scripts were developed from these outlines that were adapted into short background papers on the four deliberation areas. These scripts were then used to construct four informational videos (ranging in length from 5 to 10 minutes) that were created in partnership with NASA and a professional videographer. ECAST content developers took responsibility for the written and visual content to ensure that it could serve the deliberation needs of a diverse audience. In addition to NASA resources shared at the Boston and Washington meetings and subsequent interviews and correspondence with experts from NASA, content developers used National Academy reports, documents from the other authorities such as the European Space Agency, and other kinds of sources to inform the background materials.

Figure 2.3.3 Information video screening at the beginning of the session four

The videos and background information thus provided participants with materials to read before the deliberation day, and then reinforced these ideas with compelling and relevant video presentations. However, it seemed important to present the participants with an immersive introduction at the beginning of the day that would excite them and cover all of the issues to some degree, so that they would feel engaged and have a vision of the task before them. To that end, Museum of Science worked with NASA partners as well as with staff from the Harvard-Smithsonian Center for Astrophysics to develop a 40-minute planetarium program that kicked off the day in both the Phoenix and Boston locations.

2.5 The Online Deliberation

The goal of the online forum was to explore the extent to which it could provide alternative avenues for a self-selected and geographically diverse audience to engage in similarly designed citizen forums. The subjects debated in the online deliberation were similar to the topics assessed in the in-person forums. Due to sparse participation and insufficient data, this report did not analyze the online forum deliberation in detail, though the online results were shared with NASA partners to inform their perspectives. In the following paragraphs we briefly overview the three phases of the online forums, their focus, and opportunity for future exploration and analysis.

1. Raising Awareness – The first phase of the online deliberation involved advanced recruiting of participants to sign up for the online activities described below. A dedicated website (ecastonline.org) was launched to register people for participation in the second phase. The registration forms asked the same questions of participants as those of the in-person forums in Phoenix and Boston. During this advance recruitment phase, potential participants were contacted in two ways: a series of in-person events related to the activities of Science Cheerleader, and an online solicitation that received exposure through the NASA website, the popular science magazine *Discover,* and the citizen science project website SciStarter*.* Prior to the moderated discussions, over 300 people registered on the project web site.

2. Moderated Discussions – Facilitated discussions similar to the in-person forums were hosted on a beta platform called Zilino,[3] a web-based platform for hosting moderated, deliberative online forums. Registered users who completed the pre-survey instrument were invited to join an online deliberation that was timed to take place between the in-person citizen forums in Phoenix and Boston in November 2014. The platform posed three questions related to the in-person detection and mitigation content. Registered users selected an issue that they wanted to discuss in smaller groups. Zilino moderators seeded the small group discussions and provided prompts to assist the groups in exploring each topic. 70 people registered for the online deliberation and 32 people actively participated through comments and with some of them voting on issues.

Three in-person forum topics were used. These included the Asteroid Detection, Mitigation, and Asteroid Redirect Mission themes. Participants requested background information similar to some of the questions that were asked of NASA experts during the in-person forums. At an initial review, it appeared that the online deliberations yielded similar results as in the in-person forums. Future analysis should explore this and related prospects in greater detail.

3. Amplification – In the final phase of the online deliberation, organizers adopted another technology platform called Consider.it, also in beta.[4] All prior respondents were invited to participate via email and the site content was opened to all web visitors. The site and its content received additional promotion through Science Cheerleader, the ECAST website, listserv, and Twitter account; *Discover Magazine*; and the SciStarter website. Two issues from the in-person deliberations were presented for comments: asteroid detection and planetary defense/mitigation. All site visitors could access the background information material and could watch the video content related to the two issues. The background material included representative pro and con positions that were drawn verbatim from written participant responses in the Boston and Phoenix engagements. Content on planetary defense was identical to that of the in-person events. Visitors who completed a brief registration based on the application questionnaire could register their degree of agreement/disagreement with the pro and con positions on each issue as expressed in the

[3] http://www.intellitics.com/about/
[4] https://consider.it/

in person forums in Phoenix and Boston. They could also contribute their own comments. Results from this stage of the forum are still online at https://ecastonline.consider.it/, and were also shared with NASA experts. They are not included in this report.

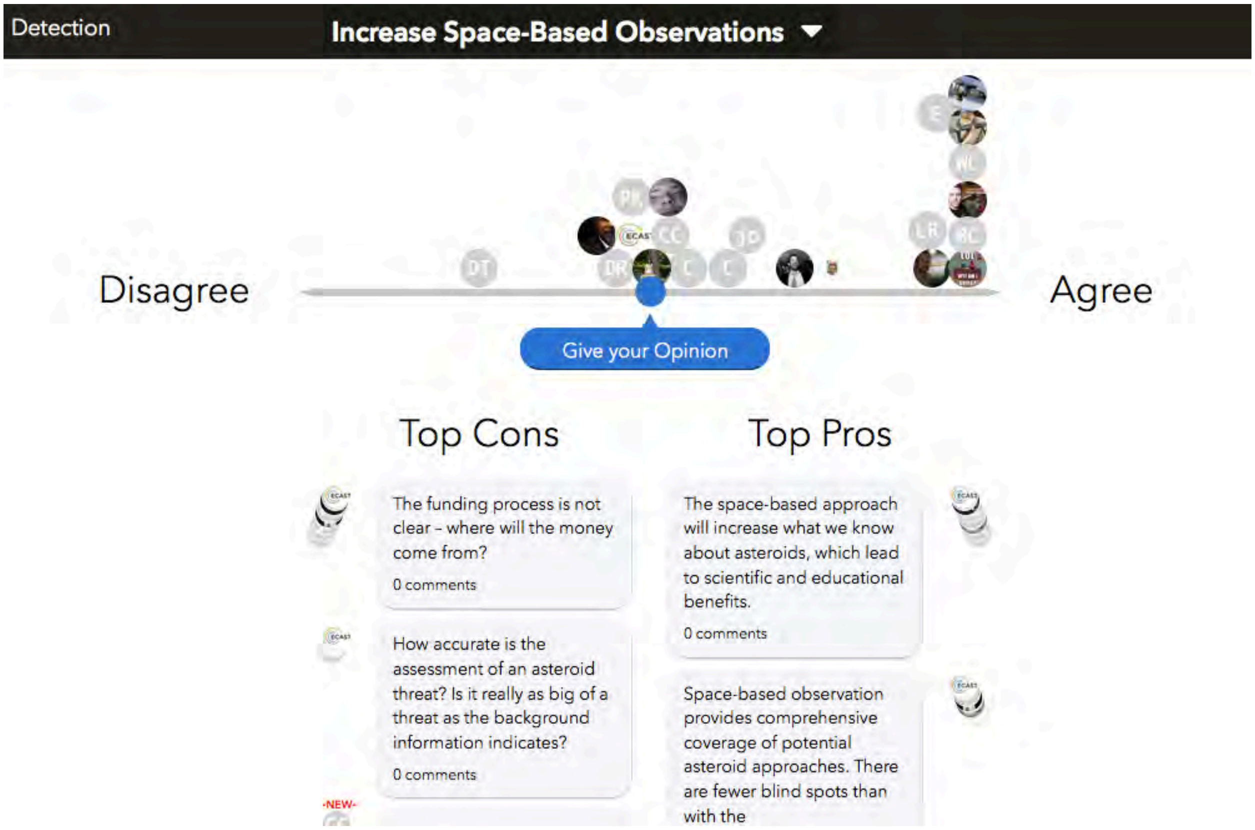

Figure 2.4 Consider.it Forum for Dissemination and Amplification of the Results

2.6 Participant and Deliberation Analysis

Understanding the meaning of the forum results depends critically on who attended, the perspectives they brought to the deliberation, and the way in which they engaged in the conversation. This and the following sections provide context on the participants who attended, which in turn provides insights into how the report should be interpreted. **Those interested in results of the forums can skip to the next sections**. However, this information does inform our analysis of those later results, particularly as analysis of the quality of deliberation affects the validity of the results. Due to time constraints on the project, this deliberation analysis is not fully integrated into the subsequent results sections.[5]

2.6.1 Selecting the participating citizens

Table 2.6 Participant Recruitment Process

Date	***Activity***
August 25 – October 18	Citizens invited to apply online via traditional media (press release, newsletter, program brochure, etc.), social media (Facebook, Meetup, Reddit, etc.), Craigslist advertisement, email campaign, and direct referrals.
October 18 – October 21	Targeted recruitment in categories with deficit.
October 21 – October 28	Selected participants asked to confirm availability.
November 3 – November 7	Confirmed participants provided with agenda, background, and logistical information and asked to complete pre-survey.

Participant Selection - During the application process, participants answered demographic questions related to gender, age, education, income, race, and ethnicity. They also answered questions related to their involvement with NASA and space related organizations:

- Have you ever attended a “NASA social” or a spacecraft launch?
- Are you a member of a space-related advocacy organization?
- Do you work with NASA or space research or technologies?

This information was used to select a pool of participants that met three basic goals:

- Select and confirm 100 participants;
- Maximize the representation of the demographic diversity of the host states (AZ and MA); and
- Minimize the representation of aerospace professionals and advocates.

A total of 286 applicants applied to participate in the November 8 Citizen Forum in Phoenix. Demographic categories where the percentage of applicants was significantly less than their respective percentages in the 2012 census data were given higher preferences in the selection process. These categories were:

[5] While it is possible to interrogate the results against the demographic profile, ideological makeup, and location of the participants from the available data for possible correlation with additional time, we make the point in section 7.1 that refinement of the forum design, such as collection of some demographic data during voting, will automatically tie individual responses to demographic patterns.

- Age 65 and above (18.6% in the population vs. 4.9% among applicants)
- No high school education (14.6% vs. 1.0%)
- Age 45-64 (32.8% vs. 17.5%)
- Hispanic (29.7% vs. 18.5%)

A total of 180 applicants applied to participate in the November 15 Citizen Forum in Boston. Demographic categories where the percentage of applicants were significantly less than their respective percentages in the 2012 census data were given higher preferences in the selection process. These categories were:

- Age 65 and above (17.7% in the population vs. 4.1% among applicants)
- No high school education (10.9% vs. 0.9%)
- High school graduates (25.9% vs. 15.2%)
- Age 45-64 (35.2% vs. 20.4%)

In addition to addressing the demographic deficits mentioned above, the selection process for both sites attempted to reach gender parity. Applicants who answered in the affirmative to the three NASA and space related questions were given lower priorities. In total, 160 applicants in Phoenix and 150 applicants in Boston were selected and asked to reconfirm their desire to participate in the forums. The reconfirmation process yielded 113 and 106 confirmed participants for the Phoenix and Boston forums respectively, of which 96 and 87 were present on the forum day. A detailed breakdown of the census, applicant, and participant data is provided in Appendix A.

2.6.2 Demographics of Participants

The validity of participatory technology assessments such as "Informing NASA's Asteroid Initiative" is based on attracting participants from a variety of socio-economic backgrounds rather than solely stakeholders with a vested interest. Therefore it is important to demonstrate that ECAST succeeded in recruiting a pool of participants that closely aligns with the general population of the event sites and limits the number of people that have had previous engagement with NASA. The following data shows that ECAST recruited a relatively neutral group (people without vested interests) of citizens to assess NASA's Asteroid Initiative.

Demographics: The distribution of participants at both sites in terms of demographic categories was closely aligned with the general population for the Arizona and Massachusetts sites. The largest discrepancy between participants and the population was in the education category, where those without a high school degree were significantly under-represented. This is frequently the case for deliberative events. However, the distribution of participants across the other educational categories (some college, bachelors degree, etc.) was relatively even (see Appendix A).

Previous engagement with NASA: The in-person component of the project was designed to limit participation by citizens who are active on space exploration issues for two reasons. First, their views are already known, because they (or people like them) are more likely to be organized to express their perspectives through advocacy groups and other channels. Second, they are more likely to dominate the conversation at the forum because others are likely to defer to the depth of their knowledge and strength of their convictions. On the other hand, such individuals do not necessarily have a pecuniary interest in space exploration issues, as might be the case for a person who worked for a NASA contractor, and in the selection process people with such pecuniary interests were not selected to participate. We therefore selected a small number of citizens with an active but not material interest in the forum topic in order to meet other selection criteria. Participants actively engaged with NASA or space issues—e.g., those who have attended a space launch or are members of a space advocacy group—were a small proportion of participants (maximum 8% in Massachusetts). While we lack reliable data on the percentage of the overall population that fits these categories, the participants in these categories were distributed evenly among the tables at the respective sites, so their impact on the discussions at a particular table of 6-8 people during the deliberations was not significant.

2.6.3 Participant Motivation and Expectations

Along with characterizing the demographics of participants, it is also important to understand what motivates people to attend a pTA forum and the expectations they have of such an event. Descriptions of participant motivations and expectations provide more contextual background for assessing to what degree people's preconceived perceptions may influence the quality of deliberation results.

The reasons that people give for attending deliberative exercises vary. To measure what motivated people to participate in "Informing NASA's Asteroid Initiative," we used pre-forum surveys and exit interviews. People participating in the forums were given 11 potential motivations for attending and asked to rate these potential motivations on a Likert scale of 1-7, where 1 = absolutely agree and 7 = absolutely disagree (see Table 2.7 for all prompts). In addition, using the same scale, we asked 5 additional questions about people's general expectations concerning participation in federal agency decision-making (Table 2.8.A) and 5 more questions about participants' general expectations about the forum (Table 2.8.B). Overall, participants did not rate each of the 11 potential motivations equally.[6] The top four reasons that motivated participants all related to learning more about various aspects of NASA's future plans. The statement "To learn about NASA's future space exploration missions" elicited the strongest agreement from the participants (mean response = 1.68, Table 2.7). Two responses worth noting are people's motivations concerning the decision-making of future NASA projects. Motivations 8 and 10 dealt with people wanting to influence decisions on NASA's future exploration missions (2.86) and planetary defense (3.08), respectively. Both mean responses to these prompts, while still indicating that these are important reasons for attending, are significantly different from reasons related to learning about NASA's future missions (Table 2.7).[7]

One reason for the lower prioritization of being involved in the event to influence decision-making may be related to people's lack of familiarity with NASA's Asteroid Initiative and future deep space exploration plans, which will be explored further in Section 2.8. However, it should be noted here that people significantly differed before (3.20) and after (4.08) the event when responding to the following prompt: "I feel I need more information in order to determine my opinion about asteroid issues"[8] (Table F-3 in Appendix F). In essence, people felt more comfortable expressing informed opinions about the Asteroid Initiative at the end of the event, which in turn could lead to people feeling more comfortable contributing to NASA's decision-making processes through deliberative events.

[6] One-Way ANOVA, DF=10, F=99.47, p<0.0001.
[7] Tukey Pairwise Test, p<0.05.
[8] Paired t-test, p<0.01.

***Table 2.7** – **Motivation:** A report of the mean responses to 11 potential motivations on a scale of 1-7 (absolutely agree = 1, absolutely disagree = 7) of participants in both Massachusetts and Arizona combined to the following prompt in the pre-survey (n=189): "What are your reasons for participating in this deliberative process?" The motivations are ranked in ascending order of most influential reasons for attending the forum.[9] Categories that don't share a letter are significantly different at p<0.05. Note: Standard deviations are reported in parentheses.*

Motivation (The original survey question order in parentheses)	*Mean Response*	*Statistical Significance p<0.05*
***1.** To learn about NASA's future space exploration missions. (2)*	1.68 (1.22)	A
***2.** To learn about NASA' s plans for planetary defense against near earth object impacts. (3)*	1.82 (1.26)	A, B
***3**. To learn about the subject of asteroid detection and planetary defense. (1)*	1.83 (1.22)	A, B
***4**. To get detailed scientific facts about NASA initiatives through an intensive dialogue with experts. (11)*	2.04 (1.35)	A, B, C
***5.** To have discussions with other people about science and technology, regardless of the topic. (9)*	2.29 (1.43)	B, C, D
***6**. To learn how I can become more involved in space-related issues in my everyday life. (8)*	2.47 (1.52)	C, D, E
***7.** To hear alternative perspectives to my personal opinion on NASA initiatives. (10)*	2.60 (1.68)	D, E, F
***8**. To influence political decisions made on NASA's future space exploration missions. (6)*	2.86 (1.66)	E, F
***9.** To be part of a national citizens' deliberation project, regardless of the topic. (7)*	2.94 (1.77)	E, F
***10**. To influence political decisions made on asteroid detection and planetary defense. (5)*	3.08 (1.68)	F
***11.** There is no specific reason why I want to participate. (4)*	5.64 (1.71)	G

The lower level of motivation for influencing NASA's decisions also could have been a matter of a general predisposition toward not being able to contribute to federal agency decision-making that people harbored before the event began. When asked on the pre-forum survey, "In the United States, opportunities for citizens to influence federal agency decision-making are plentiful and accessible," the mean response was 4.41 (Table 2.8.A). This indicates that people tended not to agree with this statement, meaning that they probably had a low expectation of being able to contribute to federal agency decisions prior to the "Informing NASA" event. This response contrasts with people's opinions on the role non-expert citizens should have in the decision-making process. All prompts concerning a citizen's place in the decision-making process of federal agencies (2, 3, and 5 – Table 2.8.A) yielded a mean response of 2.5 or below, indicating that participants believe that they should have access to decision-making processes and that they are capable of constructively contributing to these processes. In general, however, most participants had a positive outlook prior to the day (see Table 2.8.B).

[9] A one-way ANOVA indicated that participants had significantly different reasons for attending overall (DF=10, F=99.47, p<0.0001). A Pairwise Tukey Test indicates significant differences among response categories.

Table 2.8 – (A and B) Expectations of Citizen Participation in Decision-making Processes and (B) the Informing NASA forum: The mean responses on a scale of 1-7 (Absolutely agree = 1, Absolutely disagree = 7) of participants in both Massachusetts and Arizona combined to the following prompts in the post-survey (n=189): (A) "Please assess the following statements about the role of citizen participation in U.S. decision-making procedures." (B) "Which expectations do you have in terms of your involvement in the citizens' deliberation event?" Note: Standard deviations are reported in parentheses.

(A) Citizen Participation in Decision Making	***Mean Response***
1) In the United States, opportunities for citizens to influence federal agency decision-making are plentiful and accessible.	4.41 (1.70)
2) Participation of citizens in decision-making increases the quality of federal agency decisions.	2.48 (1.31)
3) Citizens are capable of developing constructive inputs for public decision-making.	2.24 (1.34)
4) Decision-making on complex scientific or technical subjects should only be the responsibility of experts.	3.98 (1.77)
5) Federal Agency decision makers should heed the opinion of citizens more than they now do.	2.49 (1.30)

(B) Expectations of Forum	
1) I expect that all participating citizens will have the same opportunities to contribute to dialogue.	2.01 (1.26)
2) I expect that I will contribute my ideas to the conversation whenever I want to do so.	2.31 (1.50)
3) I expect that I will get the opportunity to recommend changes during today's discussion about the Asteroid Initiative.	2.37 (1.32)
4) I expect that there will be some trouble in finding a common perspective among the participating citizens when discussing the Asteroid Initiative.	2.89 (1.60)
5) I expect that the NASA experts involved in the deliberation will listen to and take my views seriously.	2.32 (1.43)

2.6.4 Participant Perceptions and Satisfaction

The way the participants perceived the discussion, including whether they thought the deliberation was satisfactory, has a major impact on how one should interpret the results. If participants perceive that the outcomes of deliberations are compromised as a result of, for example, poor event organization, biases in the materials, or not having their views represented fairly in the results, then the quality of the results may not be high. In general, however, participants highly rated their experience with the forums.

To gauge participant perceptions of and satisfaction with the "Informing NASA" forum, we provided 25 prompts on the post-forum survey concerning the organization of the event (Table F-1, Appendix F) and 11 prompts concerning the outcomes (results) of the event (Table F-2, Appendix F). We asked participants to rate all of these prompts on a Likert scale of 1-7, with 1 = absolutely agree and 7 = absolutely disagree. In addition to the post-forum survey, we assessed participant satisfaction through table observations during the event and exit interviews after the event.

According to the post-forum survey, participants in general were highly satisfied with their experience at both sites. Of the 25 categories on the post-forum survey that asked about event quality (ranging from quality of facilitators to interactions with experts to logistical support), all responses to categories received mean responses below 2.2 (1 = absolutely agree, 7 = absolutely disagree). For instance, when presented with the prompt, "I am fully satisfied with the event process" (#22), the mean response was 1.36. Or when presented with the prompt, "I felt comfortable interacting with the experts participating in the event" (#23), the mean response was 1.44 (see Table F-1 in Appendix F for all responses).

The only responses that rated above a 2 were, "It's clear to me how the dialogue results will be used" (#4 – 2.16), and "Information about the topic provided by organizers was unbiased" (#14 – 2.11). While these responses are significantly different from the other 23 responses,[10] the mean responses are still relatively close to 1. Perhaps it is not surprising that people were a little less sure about how the results would be used because participants were informed that NASA would use the results in a general way without any specifics given on how NASA would use them internally. As for the perception of bias, two citizens provided written comments on the post-forum survey answer sheet about bias in the deliberation materials. There were a few mildly critical comments at the 8 tables that were directly observed by researchers (e.g., that it was not clear from the ARM video whether or not Option B would be a crewed mission or strictly robotic), but only one person noted a bias, commenting about the table cards that provided information for participants that "NASA wants us to select Option B."

In terms of quality of results (outcomes of the event), participants at both sites viewed the forum in a positive light, with most mean responses falling below 2 (Table F-2, Appendix F). The only response above 2 that wasn't a negative prompt (#2 – a prompt that is interpreted positively if most people disagree with it) was the following prompt: "I'm expecting that the outcomes from the event will receive significant attention from decision makers" (#5 – 2.39). While this is still low on the 1-7 Likert scale, it does indicate some skepticism about how the results will be used and aligns well with the slightly higher disagreement with the prompt concerning the clarity of how the event results will be used.

In general, **there were very few statistically significant differences in how participants in Massachusetts and Arizona viewed the forum**. Only four exceptions out of 36 prompts emerged. For the prompt, "It's clear to me how the dialogue results will be used" (#4), people in Massachusetts (Mean = 2.57) agreed significantly less with this statement than Arizonans (Mean = 1.79).[11] It is not clear why this effect would be more pronounced in Massachusetts than Arizona. But in general, participants in Massachusetts were slightly more skeptical about the results. For instance, participants in Massachusetts (Mean = 2.31) disagreed significantly more than Arizonans (Mean = 1.75) with the following statement: "The outcomes of the event reflected my personal perspective on the NASA Asteroid Initiative" (#1).[12] And the same pattern emerged with the statement, "I'm expecting that the outcomes from the event will receive significant attention from decision makers" (#5 – MA: Mean = 2.85; AZ: Mean = 1.98).[13]

The only other statistically significant difference between sites occurred over this prompt: "Diverse societal groups (ethnic minorities, age, and income groups, etc.) were appropriately represented in the event." People in Massachusetts (Mean = 2.09) agreed less with this statement than participants in Arizona (Mean = 1.41).[14] This difference probably can be accounted for by the demographic structure of participants at each site, as the Arizona site (53.1% non-Caucasian) had more representation from ethnic minorities than Massachusetts (27.6% non-Caucasian) (see Appendix A). However, in actuality the representation of non-Caucasians in both forums was higher than their share of the resident populations in the respective states (see Appendix A). Hence the perception could be attributable to the fact that majority of the participants resided in the greater Boston metropolitan area where the percentage of ethnic minorities is higher than their share in the population in the state of Massachusetts as a whole.

[10] One-way ANOVA, DF=14, F=14.18, p<0.0001.
[11] Unpaired T-test, p<0.0001.
[12] Unpaired T-test, p<0.001.
[13] Unpaired T-test, p<0.0001.
[14] Unpaired T-test, p<0.001.

2.6.5 Participant Knowledge and Attitude Change

One way to gauge the success of a participatory technology assessment is to determine how much participants learned during the event and to what extent the event challenged people to reconsider their social values as they relate to technology. A successful deliberation provides an environment where people have the opportunity to become more knowledgeable about a subject, but also use that newly acquired knowledge to reconsider previously held beliefs or inform their opinions about issues that they have not given much consideration to in the past. In general, the "Informing NASA's Asteroid Initiative" forum succeeded on both fronts.

We measured participant learning (Interest and Knowledge – 11 prompts, Table F-3, Appendix F) and attitude change (Asteroids and Exploration – 15 prompts, Table F-4, Appendix F) by providing participants the same prompts on both the pre- and post-forum surveys. We asked participants to rate all of these prompts on a Likert scale of 1-7: 1 = absolutely agree and 7 = absolutely disagree. Knowledge and attitude change were also assessed through participant written and voting results and through table observations, which are presented in Sections 3-6. In this section, we only present the pre- and post-forum survey data.

Interest and Knowledge – When comparing the same questions asked of participants designed to ascertain changes in interest and knowledge on the pre- and post-forum surveys, we saw relatively large changes in mean scores (see Table F-3, Appendix F). Of the 11 prompts, nine showed a significant difference before and after the event.[15] For instance, when prompted with the statement, "I am aware that there is an international near earth object detection network in place around the globe," the average response on the pre-survey was 3.14 and the average response on the post survey was 1.73. In particular, the largest increases in knowledge revolved around asteroids and planetary defense strategies (see Table 5.6 in Section 5). **What this data suggest is that people didn't come into the forum already knowing a lot about asteroids, planetary defense, and deep space exploration.**

Asteroid and Space Exploration – As with "Interest and Knowledge," the pre- and post-forum surveys had questions designed to ascertain changes in attitude toward various potential goals of ARM and space exploration. Although shifts in attitudes weren't as obvious as knowledge increases among participants, there were shifts worth noting (see Table F-4, Appendix F). Overall, 5 of 15 prompts showed a significant mean change from before and after the event.[16] For example, when prompted with the statement, "I believe that successful deep space exploration (e.g., going to Mars) depends heavily on extensive government funding and oversight," the mean response on the pre-survey was 2.93 and the mean response on the post survey was 2.41. This suggests that people's views shifted in a statistically significant way toward agreeing that support for space flight through government funding is necessary. Participants also significantly shifted their opinions toward agreeing that international agreements (#15) and international collaborations (#3) are a vital component of a successful deep space exploration and planetary defense program (Table F-4, Appendix F). These trends are also present in the participant results, which will be discussed in Sections 3-6.

Overall, participant responses on the pre-survey and post survey demonstrate that the "Informing NASA" forum had a highly significant impact on participant learning and to a lesser extent changed participant attitudes toward different ways of achieving planetary defense and space exploration goals.

[15] Paired T-test, $p<0.01$.
[16] Paired T-test, $p<0.01$.

Part II – Themes, Results and Analysis

3.0 Asteroid Detection

3.1 Background and Topic Overview

Asteroids may not seem like a big problem compared to all of our everyday concerns, but the potential consequences of a major asteroid collision are devastating. A massive asteroid impact was likely responsible for the extinction of the dinosaurs 65 million years ago. In 1908, a huge object exploded over a remote location in Siberia, killing thousands of reindeer and destroying an estimated 80 million trees over 1000 square miles. Had it struck a more populated location, the effects could have been catastrophic.

To protect against an asteroid threat, one must first be able to detect that there is a threat. Scientists estimate that they have identified well over 95% of the largest "planet-killer" asteroids of over 1 kilometer in diameter, and none of these are likely to threaten earth in the next few centuries. We know far less, though, about smaller asteroids that could cause destruction at regional or urban scales. In 2009, Congress charged NASA with the task of finding 90% of all asteroids that are 140 meters in diameter or larger by 2020, but this goal is unlikely to be achieved with current capabilities.

Better detection capabilities could improve our abilities to protect the Earth. There are already ground-based assets used for detecting asteroids, but there are limitations to that approach. First, detection is only possible at night, and we don't have coverage in much of the Earth's southern hemisphere. Also, looking up at space through the Earth's atmosphere makes detection much more difficult than it is from outer space. Weather, moonlight, and distortion from the atmosphere all present challenges to better detection. Finally, looking from Earth makes it very hard to find asteroids that are in an orbit similar to our own.

We could augment our existing capabilities from the ground by building new observatories that would increase our coverage area and allow for more standardized detection around the world. This policy might cost about $50 million annually for several decades, and could lead to new breakthroughs in other areas of astronomical research. However, it would still suffer from some of the challenges that come from hunting while down on the ground.

Many experts argue for a space-based detection system. NASA's WISE (Wide-field Infrared Survey Explorer) satellite provides some data about asteroids, but it wasn't really designed for the task and many researchers use it for other purposes. A system of one or two spacecraft could be designed and launched, with a mission of using infrared detection capabilities to identify potentially hazardous asteroids. The estimated cost of such an effort would be around $500 million per space telescope, which is much more than NASA currently receives for its ground-based detection efforts.

Any plan about how to improve our asteroid detection systems can also involve discussions of who should be involved in the governance of asteroid detection, and what level of trust the public has in those actors. Decision makers have considered who should be involved in detecting threats, including potential governmental, private, and international partners. In the forum, several groups were discussed as potential "Guardians" (institutional leaders) that would help out in planetary defense. People were asked to discuss which Guardians they valued and appreciated.

3.2 Session Mechanics

In the detection session, participants discussed three different asteroid detection strategies as well as determining which Guardians they believed should govern this process. Below are the three specific detection methods participants considered (see also Table 3-1 and Appendix G for details):

1. Keep current ground-based detection capabilities with their abilities and limitations;
2. Institute an extended ground-based network, which would be an improvement but would still have limitations, such as not being able to see sunward; or
3. Implement space-based observation from satellites, which would provide the best detection capabilities but would also cost several hundred million dollars to create, making it the most expensive option.

Organizers broke this 90 minute session into six parts, each designed to give participants a chance to become familiar with potential asteroid detection issues and strategies, building toward a group discussion that yielded each group's preferred detection strategy plan and which entity they would like to see leading the implementation of this plan. The session began with a video that reviewed the background information given to participants prior to the "Informing NASA's Asteroid Initiative" event, including the three asteroid detection strategy options. Once the video was over, facilitators gave participants thirty minutes to share their reactions to the video and discuss each of the three detection options in turn. To encourage and structure discussion, facilitators introduced a large laminated game board (Figure 3.1) and a set of cards that featured descriptions of all three detection options and the tradeoffs associated with each strategy (Table 3.1). Once the facilitators introduced the board game, they read one detection card at a time, after which participants had a ten-minute discussion that focused on the benefits and costs of that particular detection option. Both the video and facilitators emphasized that the three detection options were neither mutually exclusive nor exhaustive. Also during this time frame, participants were able to ask a panel of NASA experts further questions about asteroid detection that either clarified or went beyond the provided background information. Answers to these questions were supplied during this thirty-minute period so that they could be considered during the deliberation.

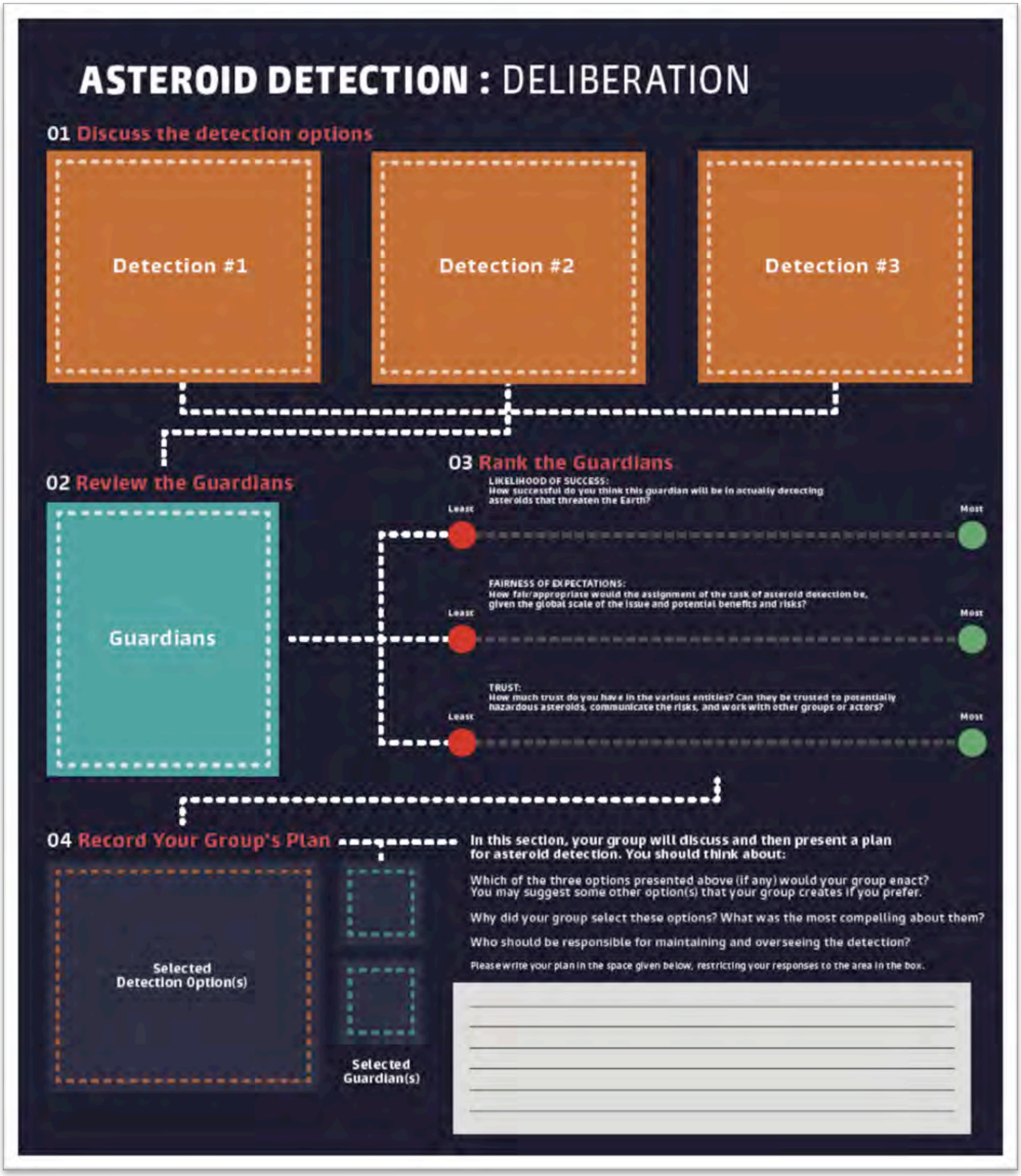

Figure 3.1 – The laminated game board used during the Asteroid Detection session to structure table group discussions about the group's preferred asteroid detection and governance strategies.

Table 3.1 – Information displayed on each of the three detection option cards.

Detection Option	*Benefits/Costs/Considerations*
***Current Detection Capabilities**: Existing observatories and communications would be supported and possibly slightly augmented in order to maintain current detection capabilities.*	Benefits • With an emphasis on communication, methods, and thus response time would greatly improve. • Opportunities could be provided for independent agencies to step up, fostering competition and innovation among private companies. • The technologies and methods are proven to work in the short term, and the potential for investing in new breakthroughs remains open. Cost • Current observatories and communications could be maintained at a low cost, perhaps $10 to $20 million annually. • Without improving our detection capabilities, we will miss potentially hazardous asteroids. Considerations • This strategy would depend upon the improved collaboration of partners with very different detection capabilities and priorities. • If resources are not maintained and degrade over time, would our detection capability fall below acceptable levels?
***Extended Ground-based network:** The existing network of ground-based observatories would be improved and expanded, especially in the Southern Hemisphere to provide additional sky coverage.*	Benefits • A large number of observatories distributes risk and ensures a consistent level of detection capabilities. • International astronomical collaboration and communication would necessarily improve. • A geographically diverse effort would promote the best observing practices and encourage mutual learning. Cost • Many new telescopes and observatories would need to be added at moderate cost, perhaps $50 million per year for several decades. • NASA may need to step in if some partners fail to produce, potentially detracting from other priorities. Considerations • Many of the existing facilities would need considerable modifications, and are currently used for purposes other than asteroid detection. • Can we rely on effective collaboration among partners with very different skills, resources, priorities, and values?
***Space-based Observation from Satellites:** One or more spacecraft would be designed and launched with a mission of using more sensitive infrared detection capabilities to identify potentially hazardous asteroids.*	Benefits • One or two space-based telescopes can provide coverage of the whole sky and find virtually all hazardous asteroids within a decade. • Being above the Earth's atmosphere allows for more accurate detection. • The telescopes could also be used for characterization of asteroid surfaces, potentially increasing our understanding of the early Solar System. Cost • This is the most expensive option at several hundred million dollars per telescope. • Having a small number of points of failure increases the chances of a significant loss of detection capability. Considerations • Might this option network reduce the dependency on reliable communication between different partners, and discourage continued investment into ground-based systems? • To what degree would this discourage collaborative scientific detection or advances in the field?

After the thirty-minute discussion about the three detection options, the facilitator then introduced the six Guardians who could be a part of a detection strategy. The term Guardian was used to talk about potential actors who could help work on and govern planetary defense, including government, private sector, academic and international actors. Using "Guardian" helped make the subject seem more accessible to a broad public audience. In order to structure the discussion, facilitators introduced a second set of cards that described the potential role of each Guardian and each Guardian's strengths and challenges for implementing a successful Asteroid detection strategy (Table 3.2). Participants had six minutes total to discuss each of the Guardians.

Table 3.2 – Information displayed on each of the six Guardian option cards.

Guardian Description	*Considerations (Strengths and Challenges)*
NASA Working Alone	• NASA is a global leader in space science, and is currently driving much of the ongoing activities to detect near-earth objects. • NASA oversees research institutions such as the Minor Planet Center and is working to implement new IR-based and robotic detection methods and develop new techniques. • However, NASA's current and future detection capabilities are threatened by budget challenges. • Further, NASA oversees a host of other space research activities, which all demand resources and expertise.
A New Office of Planetary Defense	• Some stakeholders have recommended the creation of a new office of Planetary Defense Coordination for the United States. One motivation for this idea is to allow NASA to focus upon research and operations. • This office would oversee asteroid detection and response plans, as well as coordination with national and international stakeholders. • A NASA task force estimated that such an office might require an annual budget of $250 million to $300 million per year over the next decade, as the job of finding most potentially hazardous asteroids of 140 meters or larger (mandated by Congress) is carried out. • After that, the annual budget could be reduced to approximately $50 million annually, as duties change to monitoring and maintenance.
The U.S. Leading an International Partnership	• Some people have argued that since NASA is currently the world leader in asteroid detection, it should continue to lead international efforts but that formal partnerships should be established going forward. • One motivation for this idea is to share responsibilities for asteroid detection among multiple entities. • This would allow other countries to build upon the protocols that NASA and its partners have established, but: • This option would require putting trust in other countries to detect and communicate risks around potentially hazardous NEO's.
An International Consortium that Includes NASA	• The United Nations has created an International Asteroid Warning Network, under the auspices of the United Nations Committee on the Peaceful Uses of Outer Space. • This group could be charged with the responsibility of asteroid detection, and national governments could report to it. • This would require coordination and trust between national governments, and might mean different protocols and processes from the ones that NASA has put into place already, but NASA would have some seat at the table. • One potential challenge with this idea is that it may be difficult to enforce agreements within this partnership.
Private Industry	• Private firms could be hired to implement asteroid detection. These entities could reduce government expenditures on asteroid detection. • This could increase efficiency or innovation, and also connect with potential asteroid mining activities. • This could allow governmental agencies such as NASA or the European Space Agency to focus efforts and resources on protecting the Earth from identified asteroid threats, rather than on detection. • However, private firms do not answer directly to the public since they are not part of the government. • Private firms may be motivated more by commercial interests than by an interest in planetary defense.
International Scientific / Academic Community	• Some scientists have proposed a plan to improve asteroid detection capabilities through the creation of a non-governmental organization. • The best example of this is the B612 Foundation, which is working to design and build a privately financed satellite called the Sentinel Space Telescope. • A group such as the B612 Foundation could pull in expertise from around the world, research detection and mitigation ideas and putting them into practice. • A foundation like this could function without depending on government funding. However, it could be argued that this group will not answer directly to people from any country since they are a non-governmental organization.

Once participants familiarized themselves with the six Guardians, facilitators gave participants fifteen minutes to rank in order the Guardians on the game board using the second set of cards. The ranking was based on three criteria: *likelihood of success*, *trust*, and *fairness*. This group exercise helped structure the participants' conversation about the benefits and tradeoffs of various actors and institutions leading the detection effort. It prepared participants for developing the group plan and helped participants think through their individual preferences. The informal ranking data are not available as a part of the data results, but participants did provide individual preferences through anonymous votes at the end of the session (Table 3.3).

After discussing the asteroid detection options and ranking the Guardians based on several considerations, participant groups were asked to come up with a plan. Participants were told that, for purposes of creating a plan, they could combine multiple options and did not have to exclusively pick one detection option or one Guardian option. However, in constructing their plan, groups were asked to articulate:

- Which of the three options, if any would you enact?
- What were the benefits, costs, and considerations you found to be compelling for your group's chosen option?
- Who should be responsible for maintaining and overseeing asteroid detection (i.e., your preferred Guardian)?

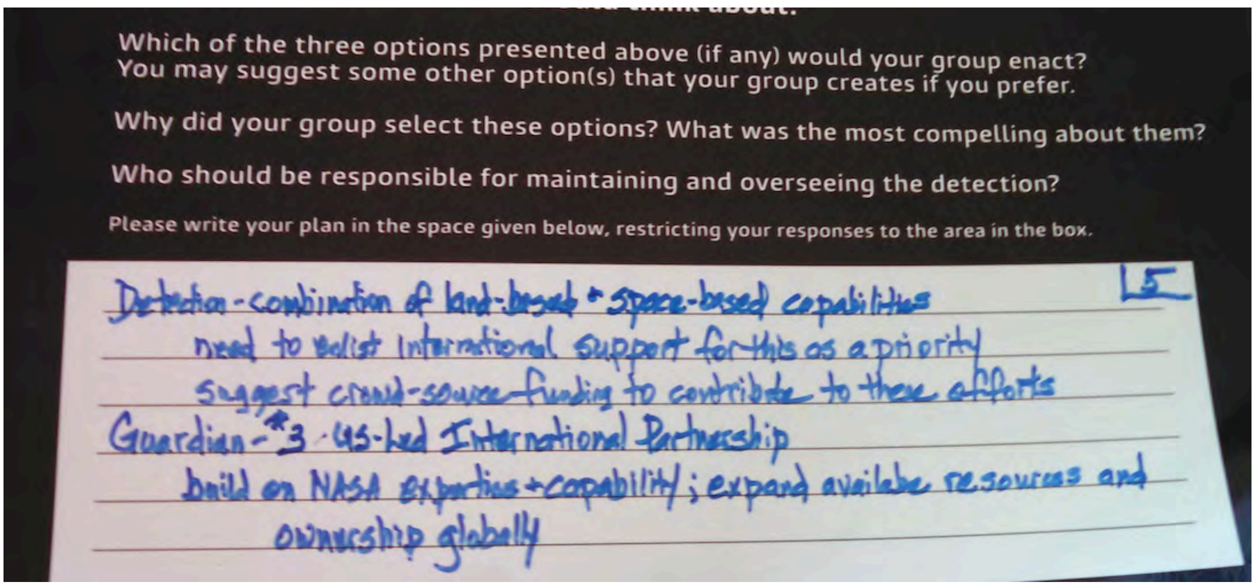

Figure 3.2 – A completed group plan for preferred asteroid detection and governance strategies.

Groups were given 25 minutes to write out their plan on a space provided on the game board (see lower right hand corner, Figure 3.2). This limited group plans to several lines of text (3-4 sentences maximum). After the group wrote the plan on the game board, facilitators turned the game boards over to the event organizers. At this point, the facilitators handed participants individual voting ballots on which participants had the opportunity to rank in order their preferred detection options and choose as many Guardians to lead detection efforts as they wanted.

3.3 Results

By a wide majority, on-site participant groups at both sites selected to implement space-based observation from satellites as a priority over maintaining current detection methods or developing an extended ground based network: 88.2% overall and 88.6% in Massachusetts and 87.8% in Arizona, respectively (Figure 3.3). Participant rationale for this selection is discussed below.

In addition to selecting a preferred detection option, participants considered and ranked their Guardians, or their preference for institutional leadership of detection operations. Participants considered the following options: NASA working alone; the U.S. leading an international partnership; an international consortium that includes NASA; private industry; and the international scientific and academic community (Table 3.3, next page). Voting patterns were generally statistically similar across the two sites.[17] The statistically significant Guardian combinations favored in both Arizona and Massachusetts were the U.S. leading an international partnership (60.8%) and an international consortium that includes NASA (57.0%).[18] There was a slightly higher preference for the U.S. leading an international partnership in Arizona (64.3%) and a consortium that includes NASA (61.4%) in Massachusetts. **An international partnership was preferred to all other options, including NASA performing the work on its own or the creation of a new U.S. office for planetary defense.** Private industry had a higher percentage ranking (34.9% combined) than NASA or a new U.S. office alone did. Because the votes were not exclusive, it's hard to assess the ranking of private industry in comparison to the other choices.

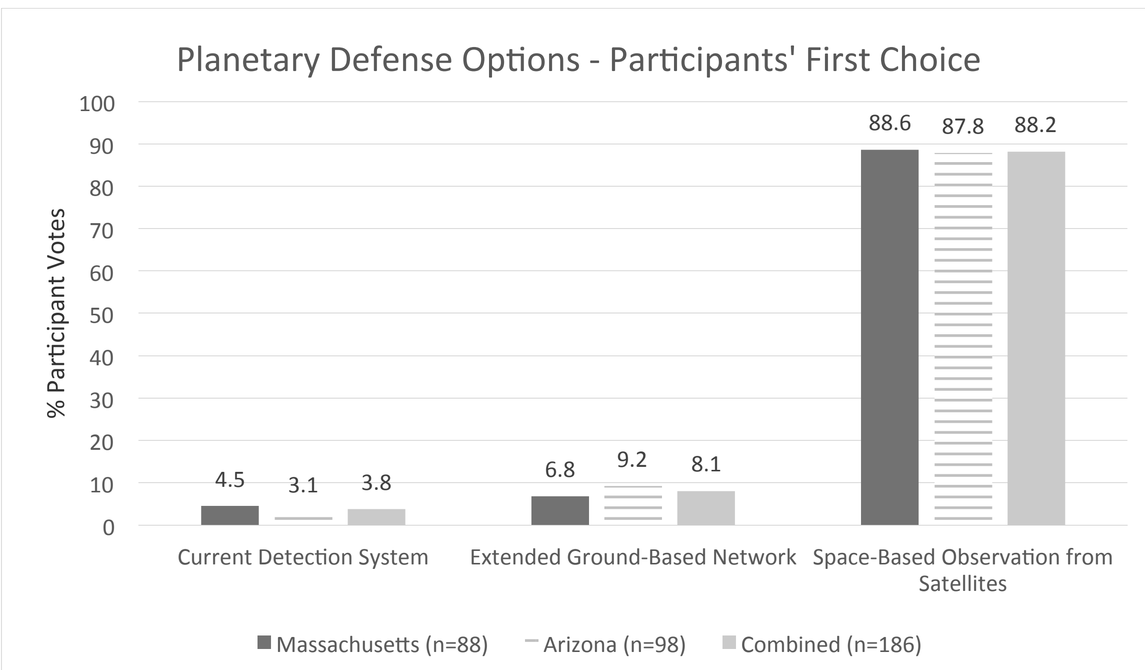

Figure 3.3 – The percentage of participants that voted for each planetary defense option as their first choice in Massachusetts (n=88), Arizona (n=98), and at both sites combined (n=186).

In the final exercise for this session, facilitators guided their groups through creating a plan for detection that would include the following three factors: 1) which of the three detection options, if any, they would

[17] In general, voting patterns between Arizona and Massachusetts participants were not significantly different (Chi-Sq. = 11.52, DF=6, P=0.07), but one category, scientific community (Arizona = 25.5%, MA = 53.4%), accounted for the only pairwise significant difference (Chi-Sq = 6.72, DF=1, p=0.01).
[18] Chi-Sq. = 93.13, DF=6, P=0.0001.

enact; 2) what the participants found to be most compelling for each option they chose; and 3) which of the Guardians should be responsible for maintaining and overseeing detection operations. **All groups prioritized space-based observation over the other choices. Brief group plan narratives provided more nuance about the relative priority of this choice over the other options. The most frequently cited sentiment was that the issue of asteroid detection is a global issue and therefore a global responsibility**. (See Table B-1, Appendix B for details on the relative frequency of different group rationales) The frequent group selection of international governing bodies with either a U.S.-led international partnership or an international consortium that includes NASA was consistent with the individual voting on Guardian prioritization shown above. Though in the minority, two tables, one in Arizona and one in Massachusetts, recommended creating a new U.S. office dedicated to the governance of asteroid detection.

Table 3.3 – The percentage of votes that each Guardian type received in Massachusetts, Arizona, and both sites combined.

Note: Percentages add up to more than 100% because participants were allowed to vote for more than one type of Guardian. One should thus interpret that the highest percentages shown were the most popular selections (e.g., the U.S. leading an international partnership is the highest combined priority with 60.8%).

Guardian	*Massachusetts*	*Arizona*	*Combined*
NASA working alone	34.1 %	22.5 %	28.0 %
A new U.S. office of Planetary Defense	26.1 %	26.5 %	26.3 %
The U.S. leading an international partnership	56.8 %	64.3 %	60.8 %
An international consortium that includes NASA	61.4 %	53.1 %	57.0 %
Private industry	36.4 %	33.7 %	34.9 %
International scientific/academic community	53.4 %	25.5 %	33.3 %
Other	17.1 %	7.1 %	11.8 %

Based on the qualitative responses recorded in the group plans, participants favored the space-based option because they perceived that this option provided the “most comprehensive coverage” and was “feasible” among the choices for detection efforts. Concerns about the economic viability, transparency, and equity associated with the selected detection strategy are also evident in the group plans. Several plans cited this method as being “a long-term investment” in detection infrastructure, rather than a cost. What is not stated in the text, but could be inferred from the prioritization of this detection mode is that through the engagement with the background material and through the videos and subsequent discussion, participants gained an appreciation of the serious nature of the hazard posed by near-Earth asteroids. In light of this, participants were willing to prioritize infrastructure that they perceived as allowing better mapping and monitoring of these objects.

Group plans also frequently cited the value of NASA and international expertise on detection, suggesting that expertise across governmental, scientific/academic, as well as industry sectors should be tapped to accomplish asteroid detection. **Plans in support of this distributed international approach cited the importance of equity and economy, such as: *"This will allow multiple groups and countries to have equal access to the data and budget costs."*** Both academic research entities and private industry also figured explicitly into some groups' planned governance structure. Two exemplary plan responses about Guardian roles were:

> *"[We selected] U.S. leading an international partnership to fund private industry and work with international scientific/academic community. We chose these guardians because it's a global issue that can benefit from private industry resources and the scientific/academic community."*
>
> *"Private industries working together with scientists will have the motivation and resources. The UN could oversee the efforts of these groups, while having the trust and authority of the world community and ability to redirect a portion of private profits."*

3.4 Discussion

The credibility of results can be assessed in several ways. The choice to select a space-based detection system raises questions of cost, and whether citizens considered cost as they made their decision. Cynically, one might assume that everyone would easily choose the most effective and "safest" option if they assumed it had no cost to them. Decision makers at NASA have to consider opportunity costs every time they make decisions, and thus the citizens' embrace of the space-based detection approach needs to be analyzed through that lens. In order to get a sense of how people considered cost when supporting the space-based option, we drew on two sources of data: the plans that each group constructed at the end of the detection session and table observations conducted by impartial observers of participant interactions during the session.

Group Plans

Due to the nature of the data, which mainly came in the form of short group plans (2-4 sentences), it is difficult to discern if people seriously considered opportunity costs. However, 18 of 27 group plans (Massachusetts and Arizona combined) did consider the absolute cost of implementing the various detection strategies. Before we consider what the group plans said about the economic costs of implementing asteroid detection strategies, we need to consult what economic information participants received in the background material and with the detection option cards.

The background information for the detection session mentioned the potential cost for the extended ground-based detection network and space-based detection, but did not provide a baseline cost for the existing ground-based detection network. It stated only that the existing network received considerably less funding than would be needed to create an extended ground-based network or develop a space-based detection system. However, participants were informed that the cost per year of implementing an extended ground-based network was estimated at "$50 million annually for several decades," whereas the cost of space-based observation was estimated at "$500 million per telescope." Along with other benefit/cost information, the detection cards provided participants with specific estimated costs for each detection option (Table 3.1). These numbers didn't contradict what was in the information booklet, but in some cases were more specific. Here is what each card said about economic costs:

- Existing ground-based network – can be maintained at $10-20 million annually (not specified in background material)
- Extended ground-based network – $50 million annually for several decades (aligns with background material)
- Space-based observation – several hundred million dollars per telescope (doesn't specifically align with background material)

Moving forward with this information along with several other points to consider, each group created a group plan. Eight of 12 group plans in Massachusetts and 10 of 15 group plans in Arizona considered cost in their plans. Groups that mentioned economic costs mostly devised a "plan" for where funding would come from without explicitly mentioning funding constraints (see Table B-2, Appendix B), typically positing that "*allocation of funds [should come] from contributors around the world.*" These sorts of statements don't explicitly deal with opportunity costs and may even imply that the issue of asteroid detection is important enough that garnering resources for such a project might not be an issue. The latter sentiment is evidenced in statements such as: "*It is an investment rather than a cost.*" This group seemed to believe that the issue is important enough that we shouldn't consider it a cost, but a matter of necessity that shouldn't be challenged on economic grounds. Also, some groups used the language of cost/benefit analysis, but generally concluded that the benefits were greater than the costs (e.g., AZ-7). However, no group mentioned the exact costs reported in the background information or on the detection cards. One group gave a dollar figure ($100 million) for space-based observation, but this was not the estimate given in either the background information or on the detection cards. They stated that at this price ($100 million), space-based telescopes would be worth the expense.

Overall, very few groups expressed concerns about how much detection strategies would cost. Only three groups (2 in AZ, 1 in MA) actually questioned whether there would be enough funds or wondered where the funding would come from (see Table B-2: AZ-2, AZ-11, and MA-3). One group in Arizona specifically asked, "*What is the impact cost to Arizona? Where would the funds draw from?*" But these sorts of direct cost questions were rare. One group did suggest cost/benefit analysis should be done on all options (MA-10, Table B-2), but at the same time concluded that the benefits outweighed the costs for implementing the space-based observation strategy.

Most groups felt that costs should be shared. The combinations of groups that should share costs often centered around private industry, international consortiums, or a combination of the two. One group even suggested "crowd-sourcing" (Table B-2: MA-5). The frequent reference to private industry in this context could be due to the fact that it was mentioned as a way to "reduce government expenditures on asteroid detection" on the Guardian cards. It is the only card that explicitly mentions any institutional leader as a source of funding. In contrast, international cost-sharing may have seemed more attractive because the Guardian cards suggested that NASA alone would have difficulty pulling off an effective asteroid detection system because of the threat from "budget challenges." The frequency of groups preferring private and international investment may also be an aversion to establishing a new government organization. The Office of Planetary Defense card was the only Guardian card that gave an explicit estimate of operation costs: "$250 million to $300 million per year over the next decade." Without a basis of comparison for how much other governance arrangements would cost, this may have dissuaded participants from choosing this institutional leader, as it had the lowest selection rate (26.3%) of all potential Guardian choices.

In conclusion, it is difficult to assess to what extent people considered opportunity costs through the group plans. During the session, cost was only one factor that groups were asked to consider when making a plan, leaving participants with limited time and space to consider details about cost. While it is clear that many groups considered cost an issue important enough to highlight in their plans, the space permitted for considering costs, or any of the other considerations for that matter, was limited. In general, due to response lengths (3-4 sentences) imposed on groups by the deliberation design, no factor was given in-depth consideration in the written responses.

Although the cost assessments presented by participants lacked nuance, this does not mean they don't have the capability to analyze this issueFirst, participants did discuss cost in more complex terms in other sessions (see, e.g., Section 4). This was especially evident when people were given the opportunity to write individual statements (participants weren't asked for individual statements in the detection session). Second, there may have been discussion about cost that occurred during the general discussions that weren't captured in the group plans. The next section explores this possibility through table observation data.

Table Observations

Another way to assess the credibility of results is to assess the nature of the interactions among the participants and the reasoning they exhibited in determining their individual and group views. Past research on participatory technology assessment has shown that if one or a few people dominate the discussion and others accede to their views, the credibility of any "group" statement can be called into question.[19] **But if participants hear one another's concerns, adjust their views on the basis of what they heard, and work together to articulate shared principles and a specific plan or view on a given issue, their expressions have a much stronger footing that can provide reliable insight about citizen views for decision makers and others.** One method for understanding these dynamics is to directly observe the conversation at a table or tables, document the results in notes or a transcript, and analyze this data to understand how the group came to its conclusions.

The rest of the discussion here will focus on an example of the deliberation that occurred at one table, highlighting ways in which it **represents the type of balanced dialog that is likely to reflect reliable insights about citizen views.** This vignette recounts one deliberation from Phoenix, showing in vivid detail both the types of reasoning and the interactions among participants that ultimately yielded a plan for international governance of planetary defense.

Vignette: One Group's Road to International Governance of Planetary Defense

In the course of the discussion, several of the seven participants adjusted their misgivings about international governance, and the plan became increasingly focused as the participants debated its specific elements.

After the informational video and the facilitator's brief overview of the issues to be addressed in the session, the first contribution of the day was made by Bob.[20] An Arizona State University student studying in a scientific field, Bob's view was that:

> *"Just from the video, the [detection option] I liked the best was the space-based satellite as opposed to ground-based … it's a little bit more expensive, but we don't have to worry about the atmosphere or things like that, and we can use the ground-based observation capabilities for something else."*

Sara quickly concurred with this view on the grounds that the space-based approach would be more effective. Unless the cost is genuinely burdensome, she reasoned that the option most likely to accomplish the program's objectives should be selected. Sara then asserted that the real waste would be investing in a ground-based approach that had a lower probability of success, turning the cost issue on its head, suggesting that money was wasted if the most expensive option was not chosen.

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[19] E.g., Emery, Steven B., Henk A.J. Mulder, and Lynn J. Frewer (2015). "Maximizing the Policy Impacts of Public Engagement." *Science, Technology and Human Values* 40(3): 421-444.
[20] Names have been changed to protect the anonymity of the participants.

Angelise supported this line of reasoning by noting that there had been no warning or detection of the Chelyabinsk asteroid, which she took as evidence of the need for an improved system. Picking up on this observation, Bob noted that detection protects all countries against the risks of an asteroid impact, so it would be reasonable to share the costs internationally. Further discussion converged on the importance of combining ground-based and space-based systems—the moderators had explicitly stated that options could be combined for the group plan.

Trusting other countries?

As the discussion moved back to the specifics of an international collaboration, Patti interjected: *"But we would have to put a lot of trust in [other countries], and this brings up the fact that we can barely trust a lot of countries these days."* This prompted practical suggestions from other participants for addressing her concern, such as assuring that a diversity of countries be involved in the international collaboration and that they elect its leaders. Their aim was to minimize the risk that the program would be hijacked to serve one or a small number of countries for purposes other than global planetary defense. Patti ultimately concurred that in principle trust was a manageable issue. Carlos and Lori made only cursory comments during this initial conversation, and it later turned out that Carlos also lacked confidence in an international arrangement because it would require trusting other countries.

Wandering in the wilderness, but finding provisions

The conversation was free-flowing over the next half hour or so, but a number of points that shaped the group's proposal came under discussion. These included:

- The program should include an *enhanced* ground detection network *and* a space detection network.
- **The main reason for international governance is to share the costs.**
- The U.S. should play a leadership role; while no participants opposed this idea, several participants doubted that other countries would like it. Various means of securing and sustaining foreign support were considered, with little concurrence.
- Private industry cannot be trusted in a leadership role (e.g., they might establish a program with government support by claiming their efficiency, and then change the price after clients had become committed to it).
- Space agencies such as NASA and the European Space Agency might be reluctant to be transparent about their activities due to nationalistic conflicts and dispositions.
- The UN should have an oversight role in order to "keep the peace" among members in the planetary defense organization, who might otherwise be disposed to competition and discord.
- A competitive space race should be avoided; a measured program development that responds to evolving opportunities and constraints would most effectively achieve its goals and would also be most palatable to decision makers over the long run.

Moving toward closure

As the discussion continued, affirmations grew for the United States agency involved in the program to be independent of NASA so that it could focus solely on planetary defense. Participants reasoned that this would limit the conflicting pressures that might take place in a large agency. An independent agency would also be less vulnerable to the congressional propensity to suddenly cut budgets, because of its small size and defense mission. However, the group struggled to reconcile conflicting goals. On the one hand, participants preferred an independent agency within the U.S. and U.S. leadership of an international planetary defense program. On the other hand, they recognized that such an arrangement could fall victim to competitive impulses that would generate conflict over priorities and less-than-transparent relations among the various countries.

After much discussion, the conversation gained more traction when the idea emerged that all parties in the international arrangement could have a similar specialized agency that would be a point of contact with their respective space agencies (in cases where the country has one), as well as with private industry and other players. Patti objected, however, that this would essentially be an arrangement in which countries would be sharing the satellite. Sooner or later, some would want to use it for different purposes. As an alternative she suggested that *"…it needs to be one office collaborating among all the countries."*

James had earlier suggested that the focus of the separate planetary defense agency in the U.S. could be strengthened by relocating all the planetary defense experts in NASA and other agencies to the new agency. Upon hearing Patti's comment, he internationalized this idea by proposing that planetary defense experts from participating countries around the world be reassigned to a single international entity, eliciting *"That's a great idea"* from one participant and elaborations of the concept from others.

Sealing the deal

Two additional ideas completed the group's plan and secured enthusiastic support of everyone but Carlos, who wanted NASA to be responsible for planetary defense independently of other countries. The first was that the new entity would have its own governing board with executive, finance, and other committees drawn from a membership of multiple countries. Hearing this, James said, *"So it would [be] run more like a business than a government."* The second proposal was that the new planetary defense agency would be a nonprofit organization.

The thread that ran through this conversation from its outset was the recognition that planetary defense would and should protect everyone on Earth. Essentially, the participants took on the challenge of accomplishing this global goal in the challenging context of a world composed of competing nations and private interests.

In the course of their conversation, the participants' plan overcame numerous hurdles. It secured the support of several participants who had little trust of other countries; defused the urge to place the U.S. in leadership position that participants could see would be unpopular among international partners; sought prospects for securing public and private funding; favored an organization composed largely of technical experts; and addressed the distractions and challenges of political influence and competition. Key milestones in the journey were:

- Establishing that the high cost of combining enhanced ground-based and space-based systems could be justified by the importance of planetary defense and its limited role in the federal budget.
- Engaging (rather than disputing) concerns over the trustworthiness of foreign nations, which transformed the issue from a potential roadblock to a manageable problem.
- Identifying seven specific issues in a free-flowing and not-particularly-focused conversation: some issues were problems to be avoided, and others were design criteria to be adopted.
- Brainstorming key features of the new agency; e.g., that it should be a nonprofit organization and that it be run like a business, not like a government.

Drawing on the transcript data at the table and the written justifications found in group plans, it appears that many group deliberations did discuss cost, but it is unclear exactly to what extent cost factored into their votes. Several tables had mentioned cost as a concern in their justifications, and some debated whether the several hundred million dollar price tag of the satellite was worth it. The vignette above approaches the issue of cost from several perspectives, but it does not provide insight on exactly how much money the citizens would ideally want to spend on planetary detection. In several places in the transcripts, some people said that the benefit to the human race was worth the several hundred million dollar cost that the material had mentioned, but would it have been worth spending even more money? In future deliberations, if we want participants to consider the costs of projects in more detail, more explicit prompts need to be created. And more time must be given to consider this issue in isolation. We elaborate on this in Section 7.2.

4.0 Asteroid Mitigation

4.1 Background and Topic Overview

The second major aspect of planetary defense includes being able to *mitigate*, or prevent, eliminate, or reduce, a potential threat. There are a number of responses that people could take to prepare and protect the Earth after an asteroid threat to Earth is identified. Each of these possible responses carries a unique mix of tradeoffs, uncertainties, risks, and costs. To date, there has been relatively less development of technologies needed to mitigate an asteroid threat. What follows is an overview of the background information participants received on some of the potential technologies and strategies that have been proposed for asteroid impact mitigation (see Appendix G for more details).

Impacts from near-Earth objects (NEOs) have occurred throughout Earth's history, and we know that these impacts are inevitably going to continue. Potential negative consequences of an asteroid collision range from harmless fireballs in the atmosphere (which occur very often with asteroids that are only a few meters across in diameter), to airbursts or dust clouds, all the way to catastrophic events with the potential for massive loss of life. The decision of whether and how people should respond to a detected asteroid threat will depend on a number of factors, including: the anticipated severity of the collision's impacts upon Earth; where and how it is predicted to impact; and the cost, uncertainty, and time associated with all of the potential mitigation responses.

Many ideas have been proposed for preparing and protecting the Earth from the threat of an imminent asteroid collision. These mitigation options vary tremendously in terms of how much each would cost; how much warning time each would require; what the risks and potential unanticipated consequences are; and how close each technique is to being ready to deploy if needed. Some could be deployed rapidly if an asteroid were detected tomorrow, while others would require huge programs to establish their readiness.

Mitigation experts have considered at least four mitigation options, most of which are not mutually exclusive (i.e., civil emergency responses could occur simultaneously with a launch of a kinetic impactor; see Appendix G for fuller descriptions):

- **Civil Defense**: Communication and preparation. Civil defense does not actually reduce the probability of asteroid collision, but rather involves notifying citizens and decision makers, and preparing people and infrastructure on Earth for the asteroid's impact.
- **Kinetic Impactors**: Ramming an asteroid. Kinetic impaction involves sending one or more large high-speed spacecraft into the path of an approaching near-Earth object. This could deflect the asteroid into a different trajectory, steering it away from the Earth's orbital path.
- **Nuclear Blast deflection**: Earth has an arsenal of many nuclear or other kinds of explosives, held by nations around the world. Some experts have proposed launching nuclear explosives from the Earth to disrupt, destroy, or redirect an approaching NEO. This may be the only strategy that would be effective for the largest and most dangerous "planet-killer" asteroids (over 1 kilometer in diameter).
- **Gravity Tractor**: If an approaching asteroid were detected early enough, it could be possible to divert its path using the gravity of a spacecraft. Instead of sending an impactor to ram into an approaching object, a gravity tractor device would fly alongside the asteroid for a long period of time (years to decades) and slowly pull it out of Earth's path.
- **No action**: This choice assumes that the risk is not worth deploying resources to mitigate.

In addition to this information, citizens were told about which options could work with different-sized asteroids, as well as how long of an advanced warning and preparation period would be needed to utilize the option.

Similar to the earlier asteroid detection session, there was also a discussion of Guardians, or potential actors who would be involved in shaping responses to asteroid threats. Participants were again asked to consider who should lead the decisions on how to mitigate. They were given the same list of Guardians they received during the detection session: NASA working alone; establish a Planetary Defense Office; a U.S.-led international consortium; an international consortium that includes NASA; private industry; and the international scientific/academic community (Table 3.2).

4.2 Session Mechanics

The purpose of the asteroid mitigation session was three-fold: 1) provide participants with information about four potential mitigation strategies that NASA or other space agencies might employ in the future; 2) present different asteroid impact scenarios and have participants evaluate which strategies they believe would be the most successful mitigation responses; and 3) have participants think about which institutional leadership (Guardian) arrangements would be preferred given different asteroid impact scenarios.

Table 4.1 – The information displayed on each of the four mitigation option cards.

Mitigation Strategy/Option	*Considerations*
Civil defense*: Civil defense does not actually reduce the probability of asteroid collision, but rather involves notifying citizens and decision makers, and preparing people and infrastructure on Earth for the asteroid's impact.*	• The costs and logistics required for preparation • The dynamics of international or regional agreements to prepare for collision • The risks of causing an unnecessary panic if the asteroid does not actually impact the planet • The tradeoffs between preparing the Earth and taking other kinds of actions to actually prevent the asteroid from reaching the Earth
Slow-push orbit change (gravity tractor): *Instead of sending an impactor to ram into an approaching object, a gravity tractor device would fly alongside the asteroid for a long period of time (years to decades) and slowly pull it out of Earth's path.*	• The potential for mission failure • The possible ineffectiveness on asteroids over 500 meters in diameter • The decades that would be needed for building, launching, and carrying out this mitigation mission • The need for prolonged detection times (20 years or more) • The tradeoffs with other mitigation and/or civil defense actions
Kinetic impactors: *Kinetic impaction involves sending one or more large high-speed spacecraft into the path of an approaching near-Earth object. This could deflect the asteroid into a different trajectory, steering it away from the Earth's orbital path.*	• The potential for mission failure • The need for detection times of at least 1 year. Chances of success increase with longer detection times. • The risk of breaking the asteroid into smaller pieces that could still threaten Earth • The cost and factors needed to accomplish the mission • The tradeoffs with other potential mitigation and/or civil defense actions
Nuclear detonation or other blast deflection: *Some experts have proposed launching nuclear explosives from the Earth to disrupt, destroy, or redirect an*	• The potential for mission failure • The need for international cooperation • The readiness of the techniques • Ethical considerations around the dependence upon nuclear

approaching near-Earth object.	detonation techniques

This deliberation lasted for 90 minutes. The background video at the beginning of the session reviewed the planetary defense and mitigation concepts discussed above, which had also been sent out before the event (see Appendix G, Session 2). Participants were given basic information on four primary asteroid mitigation options: civil defense, slow-push orbit change (gravity tractor), kinetic impactors, and nuclear detonation (or other blast deflection). On top of the video and background information, participants received cards for each mitigation option with a brief overview of the option and points to consider (Table 4.1).

Using all of this information, the **participants were asked to consider the four primary asteroid mitigation options and tradeoffs associated with each in light of three basic asteroid impact scenarios and several accompanying hypothetical variations on the main scenarios.** The scenarios, described in Table 4.2, were deliberately selected in order to survey a range of different threats, varying in four dimensions:

1. Scale of the threat: The lowest level of threat discussed included 25-100 meter asteroids, which would cause regional damage, perhaps greater than cities. The highest threat levels included so-called “planet-killers,” which would affect all of humanity.
2. Timeframe of the threat: Some threats were perceived to be 4 years away, while other threats were seen as being 20 years away.
3. Likelihood of impact: The odds of impact varied from 25% to 75%.
4. Predicted location of impact: For some scenarios, the likely location of impact was suggested. For example, North America was the impact site in Scenario 2A.

These time frames and parameters helped to tease out the relevant merits of the different mitigation methods and helped draw out people’s perceptions of risks. For example, Scenario 1 presented participants with a short-term (4-year) impact storyline that involved an asteroid of 25-100 meter diameter and a 75% probability of impact. The three hypotheticals associated with this main scenario maintained the time variable of 4-years but varied the size, location, and probability of impact. Participants voted for their preferred mitigation strategies after being presented the main scenario and after each of the three hypotheticals (4 separate votes).

When voting on their preferred strategy, participants were given the option of choosing more than one mitigation option and more than one Guardian. Event organizers also asked participants to supply a rationale for their choices. Participants voted for their preferred Guardian(s) only after the presentation of the main scenario.

After voting on Scenario 1 was complete, half of the forum participants heard about Scenario 2A (20-year, continental-scale impact) and the other half heard about scenario 2B (20-year “planet-killer” impact) (Table 4-2). As a result, each participant provided three additional votes on their preferred mitigation strategies and one additional vote on their preferred Guardian(s) given the circumstance.

Table 4.2 Scenarios and hypotheticals presented to forum participants during the Asteroid Mitigation session of the forum.

Main Scenarios	Hypotheticals
Scenario 1: *4-year impact* **A midrange NEO is detected and is estimated to be about 4 years from impacting Earth. The estimated size means that the range of impacts could vary between potentially destructive airbursts to regional scale disasters, but would probably not produce globally devastating effects.** **Object diameter: 25-100 meters; Probability of impact: 75%; Scale of impact: Regional**	**Hypothetical 1:** Imagine the probability of the asteroid impacting the Earth were estimated to be 25%, rather than 75% as described previously. Would this change your recommended mitigation strategy? **Hypothetical 2:** Imagine that two years after the original detection, scientists make an announcement that they predict that the asteroid will hit the Western hemisphere and there is a high probability of it impacting near North America. Would this change your recommended mitigation strategy? **Hypothetical 3:** Imagine that the asteroid were somewhere between 500 meters and 1 kilometer in diameter, rather than 25 to 100 meters as described previously. An impact from an asteroid this size could range between disastrous continental-scale effects to a potential global catastrophe. Would this change your recommended mitigation strategy?
Scenario 2A: *20-year scenario continental scale impact* **A NEO is detected 20 years before projected impact. The estimated size of the asteroid means that the range of impacts could extend to continental-scale disaster.** **Object diameter: 100-1300 meters; Probability of impact: 50%; Scale of impact: Continental**	**Hypothetical 1:** Imagine the probability of impact were 10% instead of 50% as described previously. Would this change your recommended mitigation strategy? **Hypothetical 2:** Imagine that two years later, scientists predicted that the inbound NEO had a high probability of impacting North America. Would this change your recommended mitigation strategy?
Scenario 2b: *20-year "planet-killer" impact* **A very large NEO is detected 20 years before projected impact. The estimated size of the asteroid means that the range of impacts includes global-scale disaster.** **Object diameter: 1-5 kilometers; Probability of impact: 10%; Scale of impact: Global**	**Hypothetical 1:** Imagine the probability of impact were 50% instead of 10% as described previously. Would this change your recommended mitigation strategy? **Hypothetical 2:** Imagine that the projected time of impact were 50-100 years away instead of 20 as described previously. Would this change your recommended mitigation strategy?

Table 4.3 Mitigation Scenarios by Technology - Participant voting patterns on mitigation strategy choice based on ten different scenarios.

Percentage votes for each strategy are Arizona and Massachusetts combined (N = 184 for all Scenario 1 hypotheticals, N = 90 for all Scenario 2A hypotheticals, N=94 for all Scenario 2B hypotheticals). The mean for each strategy is provided below (n=10, except Gravity Tractor, n=6).

SCENARIO	NO ACTION	CIVIL DEFENSE	GRAVITY TRACTOR (DERIVED FROM “OTHER”)	KINETIC IMPACTOR	NUCLEAR DETONATION BLAST DEFLECTION	OTHER (NOT GRAVITY TRACTOR)
SCENARIO 1 (4 YEAR 25-100 METER DIAMETER 75% IMPACT)	3.8	75.5	NA	66.8	56.8	10.4
1-1 (4 YEAR 25-100 METER DIAMETER 25% IMPACT)	6.0	72.3	NA	62.0	41.0	10.9
1-2 (4 YEAR 25-100 METER DIAMETER 75% NORTH AMERICAN IMPACT)	1.1	77.0	NA	62.5	65.0	5.5
1-3 (4 YEAR 500-1000 METER DIAMETER ASTEROID 75% IMPACT)	4.9	60.6	NA	41.8	85.8	9.3
SCENARIO 2A (20 YEAR 50% IMPACT – CONTINENTAL SCALE)	2.2	43.3	47.8	60.0	73.3	18.8
2A-1 (20 YEAR 10 % IMPACT – CONTINENTAL SCALE)	21.1	44.4	43.3	48.9	41.1	13.3
2A-2 (20 YEAR 50% NORTH AMERICAN IMPACT – CONTINENTAL SCALE)	1.1	46.7	35.6	58.9	75.6	12.2
SCENARIO 2B (20 YEAR 10% IMPACT – PLANET KILLER)	6.4	40.4	25.5	47.8	70.2	18.1
2B-1 (20 YEAR 50% IMPACT – PLANET KILLER)	6.4	42.6	18.1	43.6	74.5	19.1
2B-2 (50-100 YEAR 10% IMPACT – PLANET KILLER)	14.9	24.5	40.4	42.6.6	39.4	25.2

4.3 Results

4.3.1 Mitigation Strategies

Several patterns of participant strategy choices emerge when we analyze the scenarios in relation to each other (Table 4.3). Caution should be taken against combining score results across multiple scenarios, because some scenarios had conflicting assumptions about the level of threat, which did influence what the preferred options were. However, looking across all scenarios, the planetary defense strategy most commonly chosen overall was nuclear detonation (62.3%), followed closely by kinetic impactor (53.5%) and civil defense (52.7%). Participants selected gravity tractor only 35.1% of the time, with no action receiving the lowest average number of votes (6.8%).

Several high-level insights can be made, with detailed discussion below:

- Kinetic impactor was always a fairly popular option, and was the most popular option in the 4-year impact scenarios.
- Civil defense was generally popular, likely because it was not deemed to be an exclusive choice (people could vote for it alongside other options). It would make sense that people would still prepare civil contingencies in case a mitigation approach failed.
- Nuclear blast deflection became more popular when the threat level became higher, which implied the public was more willing to accept it at higher threats. The time horizon for impact did not seem to affect preferences in this regard. It is surprising that the nuclear option ranked as highly as it did.
- Gravity tractor had its highest support in long time frame scenarios (20 years out), which would make sense due to the long lead times required for the tractor to work.

Nuclear Detonation: Participant preference for the nuclear detonation blast deflection strategy varied widely, but significantly increased with the magnitude and certainty of impact in each of the three scenarios.[1] There was no clear relationship between time of impact and preference for nuclear detonation. We should note, however, that the only scenario in which participants selected nuclear detonation at a relatively low frequency (less than 45%) was when the probability of impact was perceived as low (Scenario 1-1: 25% impact probability, 41% of participants; Scenario 2A-1: 10% impact probability, 41.1% of participants; Scenario 2B-2: 10% impact probability, 39.4% of participants). But even these frequencies may be viewed as fairly high given people's typical negative attitudes toward nuclear technologies.

Kinetic Impactor: Although kinetic impactor was the most stable participant preference, participants showed the highest preference for it in all 4-year impact scenarios and 20-year impact scenarios with increased probability of impact (Scenarios 2A and 2A-2). Scenario 1 was the only scenario that showed a significantly different shift in participant preference by hypothetical.[2] Hypothetical 3, where participants chose kinetic impactor at a frequency of 41.8%, accounts for most of this statistical difference. In general, participants perceived this technology as "less risky" than the gravity tractor or nuclear detonation options (see Table 4.3). There seemed to be two separate rationales that drove participants to choose kinetic impactor at lower frequencies. The first is a perceived low probability of impact (10%). For example, participants chose kinetic impactor at a frequency of 48.9% for Scenario 2A-1 when the probability of impact was 10%. This was also the case for Scenario 2B. Second, participants voted for kinetic impactor at a relatively low frequency for all three "planet-killer" contingencies (Table 4.2).

[1] Scenario 1: Chi-sq. = 33.04, DF =3, p<0.0001, Scenario 2A: Chi-sq. =9.89, DF = 2, P<0.007, Scenario 2B: Chi-sq. =
[2] Chi-sq. =11.63, DF=3, p=0.009

Gravity Tractor: Event organizers didn't provide gravity tractor as an option in Scenario 1 because it was deemed unrealistic that this technology would be available within the time frame of 4 years. This option enjoyed its greatest support in longer-term scenarios with high probability of impact (50%). For example, gravity tractor received the largest number of votes (47.8%) with Scenario 2A (50% impact on a continental scale). We should also note that the gravity tractor option was not provided as a voting choice during the hypotheticals for 2A and 2B. Participants were directed orally to choose gravity tractor and indicate it in the "other" category if they felt the strategy was an appropriate technology to use. Regardless, participants still selected gravity tractor as a strategy at a fairly high frequency (Table C-1, Appendix C).

Civil Defense, No Action, and Other: Preference for the civil defense strategy had a clear relationship with time to impact: the sooner the impact, the higher the preference for civil defense. "No action" was always a relatively low preference across all scenarios, but did peak significantly for Scenario 2A-1 (21.1%) and Scenario 2B-2 (14.9%). The common thread between these two scenarios was the low likelihood of impact (10%) in the distant future (20 -100 years). The "other" category remained at a relatively low frequency choice, except with the "planet-killer" scenarios. Participants chose "other" in all of these scenarios at a frequency around 20%, with the "50-100 year planet-killer" scenario receiving the highest percentage of "other" votes (25.5%). Due to the long-term nature of these scenarios, people offered a variety of "creative" solutions to the "planet-killer" events.[23]

4.3.2 Mitigation Governance

Table 4.4 compares participant choices for Guardianship of Asteroid Detection (Table 3.1) with the Guardian choices they made upon reflecting on the scenarios presented during the mitigation session. For each primary scenario (4-year impact, 20-year continental level impact, and 20-year "planet-killer"), participants were asked who they thought should lead mitigation efforts.

In general, considering different scenarios led participants to significantly change who they preferred leading mitigation efforts relative to what they chose during the detection session.[24] (Column 1 of Table 4.4 repeats this data for comparison.) There was a slight tendency to move away from U.S.-led initiatives (NASA working alone, U.S. leading an international partnership), and a shift toward an international consortium that includes NASA. **More dramatically, participants' preference for private industry (34.1%) leading efforts during the detection session declined in Scenarios 1 (10.4%) and 2A (14.4%), but remained relatively high for Scenario 2B (29.7%).** Also**, the relatively high desire for the scientific/academic community as the lead Guardian during the detection**

[23] It is difficult to discern what "other" means for this analysis. The most common "other" suggestion from participants during all 4-year scenarios is to use "conventional weapons" (11 votes – all from the same table), context-dependent descriptions employing the given strategies (10 votes), and no specific suggestion given (10 votes). These 31 votes accounted for 53.4% (n=58) of other votes casted for all 4-year scenarios. Ideas that were unique relative to the majority of the votes included: underground bunkers (4-year, 75% North American impact), drill nuclear detonators into asteroid, use kinetic impactor if solid asteroid/use nuclear if rubble, solar sail, lasers, evacuation, chemical disintegration, and global guided meditation. The most common "other" suggestions for the 20+ year scenarios, "study more" (28 votes), "new technology" (19 votes), "no specific suggestion (19), "mounted rockets" (9 votes), and "ion propulsion" (9 votes – all from same table). These suggestions accounted for 84.4% (n=99) of the "other votes. Ideas that were unique relative to the majority included: drill nuclear detonators into asteroid, orbital mirrors, solar sail, laser, planetary shield, global guided meditation, light deflection, paint, YORP effect, laser for nuclear detonation target, Jupiter outpost w/nuclear detonator, evacuate to space station, and colonize mars.

[24] (Chi-sq. = 24.83, DF=6, $p<0.0001$)

session (33.3%) also diminishes considerably after the introduction of scenarios. In general, as the scenarios were introduced, participant preferences for lead Guardian narrowed in on two Guardian types: the U.S.-led international partnership (range = 50-56%) and an International collaboration including NASA (range = 60 – 76%). Of all the Guardian types, the international collaboration including NASA was the only one that showed increased participant preference during the mitigation session. Notably, participant preferences for any of the Guardians didn't significantly shift among the three main mitigation scenarios.[25] **Overall, the governance results are very interesting because they tend to show that people's predispositions toward certain governance strategies can be influenced by additional information.**

Table 4.4: Comparison of percentage of votes that each Guardian type received based on different scenarios presented during the mitigation session.

Note: Percentages add up to more than 100% because participants were allowed to vote for more than one type of guardian. The highest probability shown can be seen as a reflection of the most preferred option.

Guardian	*Results from Detection Session (No Scenario)*	*Scenario 1 "4 Year Impact"*	*Scenario 2A "20 Year 50% Impact" (Continental Scale)*	*Scenario 2B "20 Year 10% Impact" (Planet-Killer)*
NASA working alone	28.0 %	18.0%	15.5%	17.9%
A new U.S. office of Planetary Defense	26.3 %	19.7%	23.3%	14.3%
The U.S. leading an international partnership	60.8 %	50.3%	54.4%	55.9%
An international consortium that includes NASA	57.0 %	61.7%	75.6%	69.0%
Private industry	34.9 %	10.4%	14.4%	29.7%
International scientific/academic community	33.3 %	15.8%	18.9%	16.7%
Other	11.8 %	6.0%	1.1%	4.8%

4.4 Discussion

. The mitigation deliberation touched on many different issues that are of relevance to decision makers, and we strove to provide a broad overview of comments and insights.

Below, we discuss three salient issues that relate to the quality and the value of the deliberation that emerge from the results of the mitigation session:

1. First, as participants considered the different scenarios, they discussed different concerns and issues that might arise in the scenario. These data demonstrate how people come to own and interpret this information in ways that policy makers can use. Participant struggles with the complexity of mitigation shows the value of deliberations in documenting people's evolution in thinking about highly complex missions.

[25] Chi-sq. = 13.60, DF=10, p=0.192.

2. Second, we also wanted to spend some time elaborating further on why nuclear detonation was such a popular mitigation choice given the historically controversial nature of using nuclear technologies as weapons and an energy source.
3. Lastly, we wanted to spend some time exploring why people shifted their preference for guardians as the subject changed from detection to mitigation. Again, understanding such a shift is valuable in that it shows that given enough information, people can change their minds in logical ways about how technologies should be governed.

Participant Rationales and Concerns Underlying their Mitigation Choices

The different scenarios and hypotheticals the participants entertained revealed a great deal of struggle in deciding which mitigation strategies would work best under different circumstances. This struggle was in part captured by their written justification that supported their eventual mitigation strategy choice.

To explore participants' understanding of the complexity and difficulty of implementing mitigation strategies, **we analyzed participant rationales for the mitigation strategies they chose during Scenario 1 (4-year impact) and its three hypotheticals** (see Table 4.2 for overview). As discussed above, these hypotheticals involved varying threat and likelihood levels. After revealing Scenario 1, facilitators asked participants to explain their rationale for their chosen mitigation strategy(s). **Then after each subsequent hypothetical was introduced, participants were asked if they would change their strategy and if so, why. Participants were not specifically asked to write down what challenges they associated with the planetary defense strategies**, so any responses expressing challenges originate from the participant's internal reflections on their choices.[26] In some cases, the participants relied on statements that had originally been presented in the background material, which reflects their ability to consider tradeoffs and make decisions based upon provided knowledge. In other cases, they relied on conclusions that did not have a source in the background material.

Table 4.5 **– Types of concerns and rationales mentioned by citizens when choosing their mitigation strategies. We perceived twenty-eight types of concerns from written participant rationales justifying their chosen mitigation strategy choices for Scenario 1 (4-year, 25-100 m diameter object, 75% chance of impact) and the three hypotheticals (variations on Scenario 1).**

The left column entries are categories of difficulty that align with the considerations given to participants on each of the mitigation strategy cards. The right column entries are categories of difficulty that are independent of the consideration supplied to participants or elaborations on the considerations.

Written concerns that were mentioned in background materials	**Written concerns that were independent of background material**
Creating public panic	Risk to human life associated with nuclear detonation
Risk of creating fragments with kinetic impactors	Risk of creating fragments with nuclear detonation
Risk of mission failure	Risks associated with partial failure
Uncertainty about kinetic impactors working against larger objects	Inability to predict consequences of nuclear detonation
Diplomatic complexity of using nuclear detonation strategy	Problems associated with launch failure with nuclear payload
Difficulty of developing nuclear strategy/technology appropriate to the mission	What to do if fragments are created
Ethical struggle with using nuclear detonation	Matching theory with practice (general concern that reality will be harder to implement than theory)

[26] Both sites combined, we looked at 187 rationales per scenario/hypothetical (748 rationales total for 1 main scenario and 3 hypotheticals). Some participants did not supply rationales, but the majority did.

Difficulty of implementing certain strategies with a short time frame (4 years)	General uncertainty about multi-staged missions
Cost of implementing mitigation	Uncertainty about impact location makes civil defense difficult
Having enough time to prepare	Available technology is not adequate – need to find new options
	The need for education about mitigation options in relation to convincing people
	Difficulty of managing civil defense when using nuclear weapons in defense of a continental scale impact
	Composition of asteroid (solid vs. rubble) and appropriate mitigation strategy
	Civil defense/regional alerts and property values
	Technical challenges of reaching an asteroid
	Developing civil defense infrastructure
	Protection against radiation from nuclear detonation
	The tradeoffs of deflection vs. destruction of target

We found that participants regularly offered thoughts on the challenges and complexity of planetary defense. And as people's choices of mitigation strategies varied from scenario to scenario (Table 4.3), so too did their rationales and opinions on how hard it would be to defend Earth from asteroid impacts. Table 4.5 shows 28 different ways that participants recognized potential challenges. We divided the challenges into two broad categories: 1) concerns that aligned with the provided background material (Table 4.1); and 2) concerns that were independent of the background material. While many of the background considerations showed up in participant rationales, many participant concerns go beyond the list of considerations provided. For Scenario 1 alone, participants came up with another 18 concerns on their own (Table 4.5).

4.4.1 Digging Deeper into Citizen Rationales

Simply understanding how the public thought about challenges and concerns of mitigation options (Table 4.5) may be of interest to NASA decision makers. In the rest of this section, we will provide examples of participant insights for five broad categories of concerns that affected the rationale for a given mitigation strategy: 1) understanding probability; 2) the use of nuclear detonation; 3) technical complexity and challenges; 4) the politics of mitigation; and 5) the economics of mitigation.

Impact and Mission Success Probability influencing Rationales**:** Participants were presented with a spectrum of information about the scenarios that included quantitative, qualitative, and sociopolitical issues that factored into their choice of mitigation strategies. As we have stated, there is evidence to suggest that participants were able to understand, assimilate, and integrate these different inputs in a nuanced way to inform their selections and rationales. One example is a focus on how participants understood and interpreted the probabilistic information that marked differences in the mitigation scenarios.

Participants referenced probabilistic information, but did not utilize it analytically to support their decision as a statistician would. Instead, participants adopted probabilistic language anecdotally to support their selection of multiple strategies in the face of future risk at whatever the likelihood of possibility: e.g. *"Kinetic impactors and nuclear weapons aren't going to be guaranteed 100%, so a plan A and B should always be necessary"; "If there's a chance of impact, especially 25%, action should still be taken"*; *"Even a 10% probability is significant. Need to focus on option that has best chance of* *success (at lowest cost)."* Participants viewed the pursuit of multiple strategies as a way to account for change in technological capabilities and future new knowledge that could change mitigation conditions, beyond probabilistic considerations. Probability figures into risk perception, but it is by no means the most meaningful variable to participants as they weighed the uncertainties of the mitigation scenarios.

While this use of the probability information is a common theme in individual mitigation responses across the scenarios and hypotheticals, participant misunderstanding and misuse of this information is present in the qualitative responses:

> *"Since no option is 100%, a combination of all 3 selected would increase the chances of success.* [In reference to Scenario 1]*"*
>
> *"[The reduced chance of impact] actually makes strategy even more certain because lower probability.* [In reference to Scenario 1, Hypothetical 1]*"*

Future deliberation designs could better account for how statistical concepts are introduced as a component of the scenarios for consideration. **We note here, however, that participants' misunderstanding or misuse of these concepts as information for decision making in the context of the mitigation scenarios does not constitute an invalid or unusable result.** Inaccuracies in participant explanations using these concepts can point to places where communication and outreach strategies can be adjusted to assist the public and NASA's constituencies to better connect expert assessments of risk to other social, political, and environmental factors. Design adjustments accounting for these information asymmetries should make space to better capture participant understanding of the reasons and contexts for particular mission choices internal to the agency.

Nuclear Detonation Concerns as Rationales: Many of the challenges participants struggled with concerned the use of nuclear detonation as a mitigation strategy. **As was seen with the voting patterns (Table 4.3), people were reluctant to choose the nuclear detonation strategy until they were confronted with Scenario 1-3, which depicts a 75% probability of a continental-scale to planet-killer impact in four years.** However, **not all participants fell into this category. There were some who were confident that nuclear weapons would be the most successful in all scenarios, as indicated by this participant's response**: "*Nuclear weapons seem to have the highest chance of success in reducing the asteroid threat, and civil defense can deal with any fragments which may slip through."* Several others simply exclaimed, "*Nuke it!*" Nonetheless, **many participants refused to choose the nuclear option on ethical grounds for the first three scenarios, but once confronted with the 4-year planet-killer scenario, reluctantly chose the nuclear option.**

For some who chose the nuclear detonation option for Scenario 1-3 only (planet-killer), it became their only sense of hope: "*Yes, it has a chance of causing major damage. Just blast that sucker and hope for the best,*" and "*If there were going to be large-scale devastation, nuclear weapons seem the only option to ensure survival.*" The ethical dilemma was also prevalent in participant rationales: "*Ideally, I would prefer to not risk harming our planet and the people or animals that the meteor could hit. Realistically I know there are costs involved."*[27] And others relayed what they felt would be a dangerous mission, even

[27] This response assumes that radiated pieces of an asteroid would fall back to Earth. For the scenarios discussed, any nuclear detonation would likely hit the asteroid while it is still years away from impact, making the risk of impact on the Earth unlikely. This point was shared in material provided to citizens but, given the fast paced dynamics of the conversation, it is understandable that not everyone would understand that point. This issue did emerge in a relatively small number of responses. Regardless, this quote serves as an example of a participant becoming more comfortable with the idea of using a nuclear strategy.

in the face of global catastrophe: *"*DANGER, DANGER* Alert everyone. Nuclear weapons."* On a more complex level of civic engagement in relation to the use of nuclear weapons, one participant wrote: *"I do feel that nuclear technology could have value here—we might not have any other option. I think people should be educated about why these options exist. Otherwise people will created their own systems of communication and without transparency, trust in decision makers would be in serious question."* Here the participant is not only concerned about the potential panic associated with a large asteroid impact, but the way citizens would perceive the decision-making process about using nuclear weapons. If the process is not transparent, public distrust could get in the way of implementing this strategy, thus endangering the sole available means for dealing with a planet-killer impact.

On a more technical level, **some participants who only chose the nuclear option for Scenario 1-3 thought about their decision in relation to other available options**, *"The asteroid is too large for kinetic impactors now, so nuclear weapons are the best option to decrease damage risk,"* and *"In this case I would add nuclear because it is the only strategy likely to be effective against an object of this size in this timeframe."* In essence, many people felt this would be a *"last ditch effort."* And many others, **while stating that the nuclear option might be necessary, still wanted to implement other options first**: *"Yes, [this sized asteroid is] much more dangerous! But I would still rather try other options before using nuclear weapons."* **There was also a minority of participants that wouldn't give in to the nuclear options**: *"Although the size of the asteroid has changed, my suggestion is bigger and multiple kinetic impactors. If multiple impactors don't work, what justifies that nuclear impactors will cause an effect. Perhaps we need more explanation on nuclear weapons use in this scenario as I am still very confused about the use of nuclear weapons and their effectiveness."* This participant in general seemed not to trust the information given in the background material. In essence, this person questioned the level of certainty given to the nuclear strategy that many others didn't call into question, which additionally point not just to the issue of accurately communicating the probabilities and uncertainties, but also to the issue of trusting the source and provider of information.

Technical Uncertainty as a Rationale: Another concern or challenge that emerged in participant dialogues centered on a variety of technical risks associated with using the nuclear strategy. **The issue of technical uncertainty surrounding the decision was a frequently provided rationale.** For instance, one participant identified several levels of uncertainty associated with intercepting and destroying an asteroid: *"Civil defense - even if you know, you're effed. Kinetic - asteroid too large and composition unknown. It might split in half and still hit. It might not be enough momentum. Nuclear - it might break up and still cause destruction, composition unknown."* First, **this participant is uncertain how to handle civil defense in the wake of a potential planet-killer.** Second, on a more technical level, how to deal with a large asteroid is problematic, because even if you hit it, it *"might split in half."* Third, the composition of the asteroid is a concern because it is uncertain how an asteroid will behave after the use of nuclear detonation or kinetic impactors.[28] One participant, who was pro-nuclear for all scenarios, became hesitant about nuclear option for scenario 1-3 (planet-killer) because of the potential for asteroid fragmentation: *"It made me waver … unlike before. If this asteroid split, the pieces would still pose a large threat. Multiple nukes would be needed for the main asteroid and the pieces it breaks into."* In this case, this participant believed the size of the asteroid would complicate the use of nuclear detonation.

[28] As mentioned in Footnote 26, the detonation distance for kinetic impactors and nuclear makes it unlikely that pieces of the asteroid would impact Earth. Nevertheless, these quotes represent how the participants struggled with technical uncertainty in their decision.

Other participants wrestled with the complexity and uncertainty associated with actually delivering kinetic impactors or a nuclear payload to an asteroid: *"Use multiple nuclear rounds. Create crafts that can deploy the warheads so the asteroid has to 'run the gauntlet' and either get shoved or break up. Smaller remaining segments can get kinetic blasts."* **The complexity of executing a mission, while not stated explicitly, is implied by the fact that this participant saw the need for multiple missions with a variety of strategies to deal with several possible contingencies.** There were some that focused in on the issue of asteroid composition, believing that whether it was a *"rubble pile"* or solid would influence the choice of strategy: *"If the asteroid is solid, using kinetic impact won't have political implications and if it breaks into pieces, then we will be prepared with civil defense. However, if the asteroid is the rubble pile, then we would need the nuclear weapon to deflect the whole mass. Better detection methods are needed to know what the asteroid is composed of."* On top of introducing the composition issue, this participant also drew connections to detection technology, clearly seeing detection and mitigation as being necessary cooperating components of a viable mitigation system.

As seen with some of the previous examples, many participants created rationales in the form of specific contingencies: *"If the known location (approx) of where the asteroid will hit earth, I would recommend putting the most emphasis on civil defense - relocating citizens within 1-2 years of impact. If kinetic impactors have been tested and worked well in testing I would prioritize using them - if the asteroid was to be targeting a major city, I would have the nuclear weapons in place to be used."* Examples such as these show that **participants recognize that any one scenario still has a great deal of uncertainty related to it. Participants understood that there is a need to identify the many potential ways that things could play out and have multiple plans that deal with each contingency**. And still others added their own ideas: *"Rockets - we have the capability. We don't need to destroy the asteroid, just deflect it."* This likely implied attaching a rocket engine to an asteroid in a way that went beyond the provided options, which reflects an attempt to come up with new technical options.

The Politics of Mitigation as a Rationale: Many participants recognized the political uncertainties associated with developing successful mitigation strategies. While most rationales that pointed out this issue focused on the use of the nuclear detonation strategy, some saw "typical" political behavior of our leaders as getting in the way of dealing with a global emergency: *"In the past decade we have seen that government does not always have public interest/safety as a priority. It should be. Money should not be the only motivator for doing the right thing, or nothing at all."*

The brevity of the 4-year timeframe troubled one participant on political grounds: *"The short timeframe makes reacting challenging, so having an existing organization (NASA) leading the charge but drawing in the international scientific community is essential. Kinetic impactors seem the most likely to be possible to deploy in a short timeframe. Nuclear weapons present increased risks for development and launch as well as increased challenge for international collaboration."* In this case, **the participant saw having an established organization leading the mission essential to success for short-term threats. However, like many other participants, this person believed that implementing the nuclear detonation option would bring political complications with it.**

In fact, several participants chose other strategies, such as kinetic impactors, because they worried that the use of nuclear weapons would hamper mitigation efforts*: "I chose kinetic impactors because the asteroid is relatively small compared to larger ones that have been experienced. Also I believe nuclear repulsion can involve a lot of political affairs like who is going to build and who is going to foresee the construction of the nuclear weapon."* Others simply believed that leaders would have to conjure up more *"political will"* to agree on the nuclear option, especially in the event that a planet-killer is approaching. As one participant put it, *"Nuclear is the most effective in spite of political liability! Time is too short to ignore."*

In general, though, the potential for political conflict over the use of nuclear weapons and the need for international agreement weighed heavily on participants' minds when considering the use of the nuclear detonation strategy, as the following statement exemplifies: *"The main issue about using these already existing [nuclear] weapons is purely political agreement among the countries that own them."* This implies potential hindrances that may occur due to existing legal and policy regimes which might make it difficult to use nuclear weapons as a deterrent.

The Economics of Mitigation as a Rationale: For the 4-year impact scenarios, considerations of cost were fairly infrequent. There could be a couple of reasons for this. First, participants were not explicitly asked about cost, nor given significant background information about cost differences between the options. This would logically reduce the chances that a participant might mention cost as a factor in a 1-3 sentence prompt for a rationale. Second, as is indicated by some of the quotes below, **participants might have believed that the cost of a mission should be a low priority when preparing for a 4-year impact**. When cost was mentioned, there was a strong sense that no costs should be spared in protecting the planet from an asteroid impact. As one participant put it, "*Humanity should be protected at all costs …. Money should not be the only motivator for doing the right thing, or nothing at all."* Of course, this sentiment was more prevalent when a global catastrophe was possible (Scenario 1-3): *"Yes, economics and % likelihood [of impact] are less factors versus global disaster."*

By contrast, a few expressed that government-funded mitigation, when the probability of impact was low, *"would be a waste of money."* There was, however, a small contingency of participants that saw the use of nuclear weapons as a cost-saving strategy because it would entail *"low overhead costs,"* because a stockpile already exists. Along the same lines, another participant considered the costs of sending heavy payloads into space: *"Sending objects into space with large mass cost of lot of money. Nuclear weapons are light, and the US has 25,000 nuclear missiles already."* However, another participant pointed out, *"[L]aunching nuclear weapons is costly and dangerous. With low risk of impact, it's best to continually observe and change your mind if something changes in the asteroid's behavior."*

It should be noted, however, that during the longer time-frame scenarios (20 years – 2A and 2B), cost was discussed more frequently. For instance, one participant wrote: *"Yes. We now have time to consider a budget. We can choose the most cost effective option."* This suggests that, in the previous 4-year scenario, some participants felt that decision makers shouldn't make cost a high priority. If cost is an important data point to consider in future deliberations, forum organizers should ask explicit questions about cost when gathering participant rationales.

4.4.2 Two Salient Trends from the Results

We feel that there were two salient trends, among many others, that deserved a more thorough analysis: 1) the surprising support among participants for nuclear detonation as a mitigation strategy; and 2) the significant change in Guardian preference from the detection session to the mitigation session. The following two subsections provide further analysis of these trends in turn.

Why Nuclear?

As the quantitative results show, participants selected nuclear detonation with more frequency as the severity and chance of Earth impact increased. These findings emerge despite a litany of concerns that were common among the qualitative responses across the scenarios about the known and unknown risks of utilizing nuclear detonation. Many participants, even those in favor of deploying this technology, asserted that it should be used either in combination or in sequence with other mitigation technologies, or "*as a last resort.*"

Many of the reservations against the use of nuclear weapons can be observed in the responses of those who favored kinetic impactors. Examining the qualitative responses for the selection of options in Scenario 1, participants who favored the use of kinetic impactors could be grouped along several thematic rationales (Appendix C, Table C-2). Of the seventeen rationales that emerged favoring kinetic impactors, three of the top four most common responses were general in nature: kinetic impactors would be a good complement with the implementation of other technologies (1); kinetic impactors are appropriate (2); and kinetic impactors should be tried first (4). Other rationales were more specific and provide more insight into why participants favored kinetic impactors. For instance, thirteen participants felt that kinetic impactors were the most viable technology given the timeframe of a 4-year impact (3). Others saw it as a better alternative to the nuclear weapon option because they felt it would be less politically controversial (5) or simply didn't want to resort to nuclear weapons (6). There was also a fair number of participants who viewed the technology as either more readily available (7), less risky (8), safer (9), or better tested (10). These rationales, combined with the no-nuclear rationales, suggest that minimizing "risk" in general weighed heavily on participants as they were making choices for the 4-year, 25-100 meter asteroid, 75% impact scenario.

People who favored nuclear detonation also expressed concerns and fears. Many recognized the historical and political dimensions of managing this technology; participants reported that utilizing nuclear for mitigation in the context of the existing ban on space-based deployment would trigger political tensions. Other concerns centered on the uncertainty of the successful execution of the mission. Respondents noted the possibility of a launch failure accident or a premature detonation in the Earth's atmosphere. Even though the panel of experts provided information during Q&A sessions that asserted that nuclear detonation in space would not pose the risk of radiation contamination that exist within the Earth's atmosphere, some respondents were uneasy about the prospect of a nuclear blast in space. These respondents called for additional testing to determine potential impacts of this mitigation strategy.

At the same time, a number of advantages to nuclear detonation as a mitigation strategy surfaced among the individual qualitative responses recorded during voting. Participants viewed nuclear as an existing capability that has powerful effects. According to this view, nuclear detonations were needed to deal with something of a large size and high probability, and its effects would be "faster" and cheaper relative to the other methods. It is not clear whether this perception stems from information in the background materials, mitigation cards, or whether participants associate these qualities with nuclear because it is an existing, known technology. The mitigation cards and background material stated that one had to consider the costs of carrying out kinetic impactor missions, but no absolute costs were mentioned in relation to the nuclear option (Table 4.1, Appendix G – Section 2). It is quite possible that participants inferred from the cards and background information that it would be more expensive to use kinetic impactors because the technology had not been developed on a large scale yet. Nonetheless, one person expressed the advantage of nuclear as a technology that has proliferated and is available to use for this purpose:

> *"We have plenty of nukes and if the asteroid were aiming at my city I would want the threat to be removed even if it's 25%. The cost of impact on a metropolitan area would be enormous compared to the cost of a nuke.* [Scenario 1, Hypothetical 1]*"*

Though nuclear detonation for the purpose of breaking up a NEO has not been tested in outer space, participants often assert this strategy is likely to work to break up a large asteroid. One participant remarks that this solution is likely to be "*100% effective*"; another calls it the most "*protective*" option. Information about the variability and uncertain nature of asteroid composition also informed participant perceptions about the advantages of nuclear. Some perceive that a nuclear blast could be effective in eliminating smaller rubble that remained an impact threat when larger objects have been perturbed or broken into lesser pieces. These perceived advantages may stem from how participants absorbed and discussed background information provided at the forum, as well as their prior knowledge of the potential uses and force embodied in nuclear technologies both for weapons but also for power generation.

As the size and impact probability of an asteroid increased in the scenarios under evaluation, participants chose nuclear because they perceived this strategy would be most effective at averting global devastation—e.g. "*no action is unacceptable*." As in Scenario 2B, the planet-killer variant, although the chance of impact was only 10%, the fact that the asteroid was so large caused many to take a "by all means necessary" stance to protect Earth with regard to mitigation techniques. Among these, nuclear was perceived to be "the strongest" or "most effective." One participant noted that using nuclear weapons under these circumstances was a "good use" of this technology:

> *"When the survival of the planet and human race is at stake, no mitigation technique should be held back, and the strongest techniques available (nuclear) should be used. Need to build up infrastructure at NASA launch sites to handle nuclear weapons. If crewed exploration is possible, do that and leave nuclear weapons in peace."*

While we have suggested that the qualities of nuclear detonation that participants identify as advantageous are due to nuclear being an existing technology, there is also ample evidence that our respondents left open the possibility that new technologies in the future may change our mitigation options. Longer timeframes associated with the likelihood of a NEO impact elicited more comments that science and technology may change to provide better mitigation solutions.

Why the Shift towards International Governance?

During the mitigation session, participants were asked to revisit who they believed should govern planetary defense in light of the various mitigation scenarios**. From the detection session to the mitigation session, we detected a significant shift toward international collaboration as the primary governance strategy (Table 4.4). It is difficult to determine exactly why this shift occurred because participants were not asked to individually justify their governance choices during the mitigation session.** However, there are two sources of data in which we can find evidence for why this shift occurred. First, table observers recorded patterns of rationale development during the detection session (see Section 3 results). Second, participants did comment on governance issues when prompted to give rationales for choosing mitigation strategies. Using these data sources, **we hypothesize that the shift toward international collaboration occurred for two reasons. 1) The possibility of having to use nuclear detonation as a potential mitigation strategy led participants to recognize the need for negotiations among countries at the international level. 2) On a more general level, once confronted with impact scenarios that potentially depict real-life situations, participants began to see the social, political, cultural, and technical complexity of implementing mitigation strategies, necessitating, in their minds, the need for international collaboration** (see Section 3 results for an example of how this thinking evolved at one table).

When analyzing the participant rationales for the mitigation strategies they chose in Scenario 1, we found 27 instances where people included something about governance in their rationale. Of the 27, 26 were written in relation to the use of nuclear weapons as a mitigation strategy. Most of these rationales centered on the possibility of international conflict if decision makers chose the nuclear option. For instance, a typical participant response if the nuclear option was chosen was: *"International policy would need to be changed and international consensus would have to be on similar planes."* However, some participants saw the nuclear option as a barrier to successful mitigation: *"I chose against the partial option* *of nuclear attack because of political issues."* Many felt that no matter how much cooperation was sought, *"nuclear weapons would be more politically divisive*." However, especially during the hypotheticals where the probability of impact was higher and the size of the asteroid was larger, many participants expressed that we should proceed with the nuclear detonation option, despite potential political controversy.

Another shift we noticed in who people preferred governing planetary defense **was a tendency to move away from a U.S.-led mission toward international collaboration (Table 4.4).** There weren't many specific responses that speak to this pattern, but one participant commented, "*If this [nuclear detonation] was thought to work, I do not think the U.S. would want the 'fall out' politically from nuclear use***."** **This person's statement implies that it would be better for the United States to share the political liability of launching nuclear weapons into space with the international community**. However, the opposite sentiment was also present, as one participant shared, "*Politically, U.S. will more likely need to take responsibility of this concern and nuclear option would probably be most effective with that short period of time.*" This participant seems to be concerned with **the 4-year time frame of Scenario 1, which wouldn't leave enough time to embark on negotiations with other countries** and develop technical capability on an international scale. Nonetheless, we believe the prevalent presence of nuclear weapons in relation to rationales containing governance considerations suggests that putting nuclear weapons on the mitigation strategy table partly explains why participants shifted toward international collaboration during the mitigation session.

5.0 Asteroid Redirect Mission

5.1 Background on the Asteroid Redirect Mission Downselect

The Asteroid Redirect Mission (ARM) was announced in April 2013 as part of President Obama's Asteroid Initiative. The idea was seen as a way to implement President Obama's 2010 goal for astronauts to visit an asteroid by 2025. In short, the mission as originally proposed involved sending a vehicle, the Asteroid Robotic Redirection Vehicle (ARRV), to **dock with a small (10 meter diameter) asteroid, to envelop the asteroid in a bag, and then use a constant propulsive force to control the trajectory of the asteroid and slowly put it in the orbit of the moon over the course of several years**. The asteroid would be inserted into a distant retrograde orbit (DRO) where it could remain for several hundred years. Once there, the crewed portion of ARM would occur. **Astronauts on an Orion crew capsule would be launched from a Space Launch System rocket and would rendezvous with the ARRV and the captured asteroid. Once docked, the astronauts would unfold the bag, collect samples and do other research on the asteroid**.

NASA's plans for this mission continued to evolve after it was first announced.[29] It soon became apparent that an alternate mission concept might be worth pursuing. In 2014, NASA began focusing on two options for accomplishing ARM, an Option A and an Option B. **Option A (where "A" might stand for "asteroid") was essentially the same as the initial ARM proposal described above for capturing a roughly 10m diameter asteroid with an inflatable bag.**[30] It was known from the beginning that identifying target asteroids that would match the right orbital trajectory needed for redirection might be difficult, and it could be difficult to accurately predict in advance what the material characteristics of the asteroid would be. The characteristics of the asteroid can influence what scientific questions may be studied with the sample, which meant that uncertain composition could make prediction of scientific value difficult.

The desire for greater certainty on what the target asteroid would look like, as well as desire for more candidate options, led to Option B (which some refer to as the "B" for "Boulder" option) being developed.[31] This option involved traveling to a larger asteroid, greater than 100m in diameter. Previous probes to asteroids such as Itokawa have shown that large asteroids have numerous boulders resting on their surface, loosely held in place by a slight gravitational attraction. **The ARM Option B concept involved sending a probe to the larger asteroid, where the probe would descend to land on the asteroid, landing just above a boulder.** The probe would use a set of robotic arms to grab the boulder, secure it, and remove boulder using propulsion. The probe would then move the boulder to DRO around the moon, where astronauts could dock with it.

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[29] Gates, Michele, and Brian Muirhead, Bo Naasz, Mark McDonald, Dan Mazanek, Steve Stich, Paul Chodas, Jim Reuter. 2014. "NASA's Asteroid Redirect Mission Concept Development Summary." Paper given at IEEE Aerospace, March 8, Big Sky, Montana. 978-1-4799-5380-6/15.

[30] Muirhead, Brian. 2014. "Asteroid Redirect Robotic Mission (ARRM) Concept Overview: Briefing to SBAG" Presentation given at the Small Bodies Assessment Group, July 30 meeting in Washington, DC. Available at: http://www.lpi.usra.edu/sbag/meetings/jul2014/presentations/1030_Wed_Muirhead_ARM_OptionA.pdf

[31] Mazanek, Dan. 2014. "Asteroid Redirect Mission (ARM) Robotic Boulder Capture Option (Option B)" Presentation given at the Small Bodies Assessment Group, July 30 meeting in Washington, DC. Available at: http://www.lpi.usra.edu/sbag/meetings/jul2014/presentations/1030_Wed_Mazanek_ARM_OptionB.pdf

As ECAST began work on developing the citizen forum in summer 2014, NASA announced that it would do a downselect of the ARM options in late 2014 or early 2015. The ARM mission downselect was to choose explicitly between Options A and B. The comparison between ARM Option A and B was complex, with more detail being included in Appendix G, Part 3. The following material summarizes the background material given at the forum.

At a top level, both options would develop solar electric propulsion (SEP), which was the primary goal for the mission. SEP is a critical tool needed for human spaceflight missions, as it would make possible sending large volumes of payload to Mars with significantly less propellant, thus lowering the number of costly launches needed for exploration. Options A and B were equally beneficial in this respect. Option A would ostensibly retrieve the larger sample, but because of the technique's inability to accurately gauge the physical composition of the asteroid prior to capture, the mission potentially could retrieve a sample less than half the size of the targeted 10m diameter, leaving its scientific value uncertain. In comparison, Option B would involve challenges with removing the boulder from the surface of the asteroid.

Despite these tradeoffs, both would provide benefits for helping with planetary defense, but in different ways related to each method's technological capabilities. Option A could utilize an ion beam deflector and a so-called gravity tractor maneuver.[32] Option B could use the additional mass of the boulder to do what is known as an enhanced gravity tractor, where its influence would be significantly enhanced by the mass of the boulder. (In the background information, Option B was described as more beneficial for planetary defense for that reason). Option B was also envisioned as having a use extensible to going to Mars, as it could be used to retrieve samples from the moons of Mars, Phobos and Deimos. Option A has been discussed as having potential dual-uses for orbital debris removal from Earth orbit. **Initial NASA estimates showed that the cost of both options would essentially be the same, with both costing less than $1.25 billion, meaning that cost was not a deciding factor between the two options.**

The uncertainties involved when comparing the two options varied in nature. Some uncertainties, as discussed above, are technical in nature. But other uncertainties, such as how to value the larger size of the Option A asteroid, the potential extensibility to Mars missions, the potential dual-use for space debris removal, and the potential benefits for planetary defense, are all influenced by social values. The social value dimension of the ARM downselect made it a valuable assessment candidate for the "Informing NASA's Asteroid Initiative" forum. **ECAST gave NASA an interim report on the ARM portion of the deliberation in December 2014, providing it as background information for NASA's consideration prior to its making a decision about ARM Option A and Option B.**[33]

5.2 Session mechanics

This session solicited both group and individual preferences for ARM Options A or B:

- **Option A**: capture of an entire ~10 meter asteroid with an inflatable bag system
- **Option B**: retrieval of a smaller (1-3 meter) boulder from the surface of a much larger (~100m) asteroid using a robotic "grabber"

The ARM session had five components and ran for 60 minutes. The background video had two sections, with the narration included in Appendix G, Section 3. The first section introduced the Proving Ground

[32] For more info on gravity tractor, see the appendix section on mitigation / planetary defense.
[33] In April 2014, NASA announced that it chose Option B for the Asteroid Redirect Mission, but discussion of that decision is outside of the scope of this report. Assessing the role that the pTA data may have played in informing that decision could be a subject for future research.

strategy, and how the Asteroid Redirect Mission fits into this framework. The second segment outlined the tradeoffs between the two potential mission scenarios for ARM.

After the video, participants were given fifteen minutes to deliberate and share their reactions to the video. Facilitators at each table specifically asked participants to discuss the tradeoffs between Options A and B, guiding the conversation to particular comparison points such as potential scientific benefits and relevance to future exploration. After discussing the options, the participant had an additional 10 minutes to develop a written group recommendation for one of the two mission profiles and provide a rationale behind their choice (Table 5.1). In addition to the group recommendation, facilitators asked participants to vote individually and provide personal rationales for their preference (Box 5.1).

Box 5.1 – Part 1 of the individual voting ballot used during the ARM session.

Individual Voting sheet: Asteroid Redirect Mission

Which mission profile is a better choice, given NASA's Proving Ground strategy?

_____Scenario A: Inflatable bag capture of ~10m asteroid
_____Scenario B: Retrieval of smaller boulder from large asteroid with robotic arm

What were the primary reasons for your choice?

Please rank the Asteroid Redirect Mission in terms of how well it fits with NASA's Proving Ground Strategy for future Exploration:

1 Doesn't fit at all
2 Fits very poorly
3 Fits poorly
4 Fits nicely
5 Fits very well
6 Fits extremely well

Why did you choose this ranking?

After supporting one of the mission options, the facilitator highlighted the Proving Ground strategy and asked participants to discuss the Asteroid Redirect Mission in terms of the future of human spaceflight. These results are reported in Appendix D (Table D-1). The main deliberation point was whether ARM fit well with the Proving Ground strategy.

At the end of the session, the facilitators presented participants with two additional sets of questions, which were designed to get structured input that could be relevant to a technical decision and the way NASA might frame future missions. These questions addressed issues that weren't directly discussed, but were related to the conversations that took place during the ARM session. The first set of questions related to what participants perceived would be the most important goals of the Asteroid Redirect Mission and the second set of questions assessed people's levels of tolerance to potential risks associated with ARM (see Box 5.2).

Box 5.2 – **Part 2 of the individual voting ballot used during the ARM session.**

Asteroid Redirect Mission (part 2)

01 Please rank the following goals of the Asteroid Redirect Mission in terms of what you believe are the most important goals on a scale of 1-7
1 = highest priority, 7 = lowest priority

- ☐ Advancing technology needed for human spaceflight
- ☐ Advancing science
- ☐ Performing an exciting mission
- ☐ Redirecting an asteroid that no one has been to before
- ☐ Developing the economic potential of asteroids
- ☐ Advancing planetary defense
- ☐ Engaging with commercial and international partners

Exploration involves accepting that a mission may have unpredictable outcomes and may not successfully meet all its goals. The Asteroid Redirect Mission will advance propulsion technologies that are needed for future deep space explorations regardless of whether the mission succeeds.

Given that there is an inherent uncertainty of success in any exploration, how do you feel about the following possible outcomes of the Asteroid Redirect Mission? Please rank the acceptability of each potential scenarios below on a scale of 1-5
1 = acceptable, 5 = unacceptable

s01 The Option A (inflatable bag) probe retrieves an asteroid, but the asteroid is spinning so fast that it can't be controlled. The probe returns to the moon and may be used in future Proving Ground missions.

○ 1 ○ 2 ○ 3 ○ 4 ○ 5

s02 An ARM probe successfully proves that it can use gravitational deflection to move asteroid, but it is not able to capture it.

○ 1 ○ 2 ○ 3 ○ 4 ○ 5

s03 The Option B (boulder removal) probe arrives at a large asteroid to remove a boulder, but the boulder cannot be removed. The probe returns to the moon and may be used in future Proving Ground missions.

○ 1 ○ 2 ○ 3 ○ 4 ○ 5

s04 A crewed mission is launched without fully qualified life support systems, since this will allow for an earlier launch date to Mars.

○ 1 ○ 2 ○ 3 ○ 4 ○ 5

s05 Injuries occur during the broad campaign of Mars exploration.

○ 1 ○ 2 ○ 3 ○ 4 ○ 5

s06 Loss of life occurs during the broad campaign of Mars exploration.

○ 1 ○ 2 ○ 3 ○ 4 ○ 5

5.3 Results Contrasting the ARM options

5.3.1 Downselect — Group and Individual Responses

On-site participant groups selected Option B overall. The Massachusetts site groups were unanimous in selecting Option B, while Arizona participant groups were split, with nearly two-thirds of the groups selecting Option B. Two groups at the Arizona site did not reach an agreement on either option (Table 5.1).

Table 5.1 – Group votes for ARM option A or B. Group size ranged from 6-8 participants.

Site (Number of Groups)	Option A	Option B	No Agreement
Massachusetts (n=12)	0	12	0
Arizona (n=15)	4	9	2
Combined (n=27)	4	21	2

The individual voting followed a similar pattern to the group voting, with people in Massachusetts almost unanimously choosing Option B (90.7%) and 62.4% of people in Arizona selecting Option B. In general, people in Arizona were more equivocal about which option they would recommend than in Massachusetts (Figure 5.1). Overall, the individual voting pattern between Arizona and Massachusetts was significantly different.[34] When the votes at both sites were combined, participants chose Option B (76%) at significantly different frequency[35] than Option A (24%).

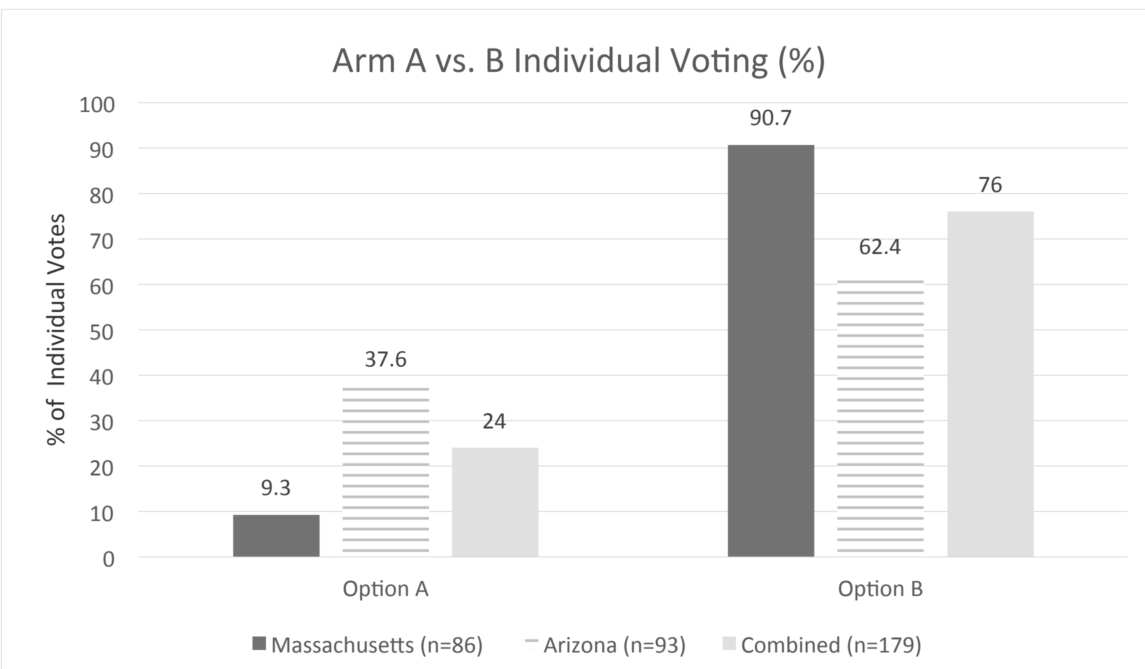

Figure 5.1 – The percent of participants in Boston (n=86), Arizona (n=93), and both sites combined (n=179) that voted for ARM option A or B.

[34] Chi-sq. = 19.65, DF=1, Fisher's Exact Test p=0.00082.
[35] Chi-sq. = 48.32, DF=1, p<0.0001.

Group rationales for selecting either Option A or B varied considerably (see Tables D-1, D-2 and D-3 in Appendix D for details).

In terms of those who voted for Option B (boulder grab), the following rationales were commonly found among groups (Table D-1, Appendix D):

- **Better control over selection of asteroid type and unknown factors;**
- **The approach has broad appeal;**
- **More obvious economic benefits;**
- **More near-term benefits;**
- **Builds on proven technology; and**
- **Fits better with the Proving Ground strategy.**

In terms of those who voted for Option A (inflatable bag), the following rationales were found among groups (Table D-2, Appendix D):

- **The approach has multiple uses;**
- **Economic benefits; and**
- **Less risky than Option B.**

The rationale of the two groups that couldn't come to an agreement was based on their beliefs that exploration should be left to private industry (Table D-3, Appendix D).

5.3.2 Quantitative Ranking of ARM Goals and Acceptability Scenarios — Individual

Event organizers also asked participants to weigh in on the potential goals of ARM. Participants had been given a mix of seven different goals that NASA managers should consider when deciding on the ARM mission. On average, **participants at both sites essentially tied in choosing the same top goals for ARM: "Advancing science," "Advancing planetary defense," and "Advancing technology needed for human spaceflight." This result indicates something about the relative importance of planetary defense, especially in contrast to other economic or international goals.** People in Arizona chose "Advancing science" as their highest priority, whereas people in Massachusetts selected "Advancing planetary defense" as their highest priority. However, the difference in mean scores between the sites on these priorities was not significant (Table 5.2).

There is a clear difference in mean scores between the three top goals and the bottom four goals, as assessed by the participants.[36] For instance, the average difference in scores at both sites combined for the third-highest priority ("Advancing human spaceflight," 2.77, SD = 1.62) and the fourth-highest priority ("Redirecting an asteroid that no one has been to before," 4.38, SD = 1.81) is 1.61. The average difference among the top three priorities is only 0.16 (Table 5.2). The lowest-priority goal at both sites was "Performing an exciting mission."

[36] One-way ANOVA, $F=108.67$, $p<0.0001$.

Table 5.2 – Participant average priority rankings of seven potential goals of the Asteroid Redirect Mission on a scale of 1 – 7 (1 = highest priority; 7= lowest priority).[37]

Below the goals are arranged in ascending order from highest to lowest priority based on voting in Massachusetts and Arizona combined. The voting in Massachusetts and Arizona are fairly consistent. The letters in last column refer to the "Combined" category. Categories that don't share a letter are statistically significantly different.

GOAL	MA	ARIZONA	COMBINED	P<0.05
ADVANCING SCIENCE	2.76 (1.40)	2.51 (1.78)	2.63 (1.62)	A
ADVANCING PLANETARY DEFENSE	2.54 (1.81)	2.85 (1.63)	2.71 (1.72)	A
ADVANCING TECHNOLOGY NEEDED FOR HUMAN SPACEFLIGHT	2.65 (1.40)	2.87 (1.78)	2.77 (1.62)	A
REDIRECTING AN ASTEROID THAT NO ONE HAS BEEN TO BEFORE	4.01 (1.82)	4.71 (1.73)	4.38 (1.81)	B
DEVELOPING THE ECONOMIC POTENTIAL OF ASTEROIDS	4.67 (1.45)	4.36 (1.85)	4.51 (1.69)	B, C
ENGAGING WITH COMMERCIAL AND INTERNATIONAL PARTNERS	5.00 (1.54)	4.86 (1.56)	4.93 (1.55)	C
PERFORMING AN EXCITING MISSION	6.05 (1.26)	5.68 (1.71)	5.86 (1.52)	D

The last task for participants in this session was to vote on acceptability of different types of mission failures and risk associated with harm to human life. They were given six different scenarios involving either a mission failure or harm to human life. Participants were asked to rate these situations on a scale of 1 (acceptable) to 5 (unacceptable). In general, participants seem to be unsure about the risks they were willing to accept. Most mean scores (at both sites combined) in Table 5.3 range between 2.61 and 2.91, indicating that **many participants were hedging slightly toward accepting risks in most scenarios**. The exceptions to this pattern were participants' relatively increased acceptance of "injury" (2.13) and partial success of gravity tractor technology (2.28). Also, **participants clearly didn't accept launching a mission "without a fully qualified life support system" (4.28)**.

[37] A one-way Analysis of Variance indicated that participants perceived the goals as significantly different from each other overall (DF=6, F=108.67, $p<0.0001$). A Pairwise Tukey Test indicates significant differences among response categories. Categories that don't share a letter are significantly different at $p<0.05$. Note: Standard deviations are reported in parentheses.

Table 5.3 – Average participant responses on a scale of 1-5 (1 = acceptable; 5 = unacceptable) to the following scenarios concerning the potential risks of ARM: "Given that there is an inherent uncertainty of success in any exploration, how do you feel about the following possible outcomes of the Asteroid Redirect Mission?"

Scenario	*Massachusetts*	*Arizona*	*Combined*
The Option A (inflatable bag) probe retrieves an asteroid, but the asteroid is spinning so fast that it can't be controlled. The probe returns to the moon and may be used in future Proving Ground missions.	2.92	2.52	2.72
An ARM probe successfully proves that it can use gravitational deflection to move an asteroid, but it is not able to capture it.	2.12	2.42	2.28
The Option B (boulder removal) probe arrives at a large asteroid to remove a boulder, but the boulder cannot be removed. The probe returns to the moon and may be used in future Proving Ground missions.	2.70	2.55	2.62
A crewed mission is launched without fully qualified life support systems, since this will allow for an earlier launch date to Mars.	4.29	4.26	4.28
Injuries occur during the broad campaign of Mars exploration.	1.72	2.49	2.13
Loss of life occurs during the broad campaign of Mars exploration.	3.02	2.81	2.91

5.4 Discussion

Participant reasoning in support of ARM Option A or B showed thematic patterns. The question of ARM A vs. B appears to represent a public decision on which option they prefer.[38] These thematic patterns, obtained from the voting data and table observations, show the dominant reasoning participants used to evaluate the proposed ARM options.

[38] In earlier drafts of this report, we had significant discussions about whether including a deliberation component that asked participants whether ARM fit within the Proving Ground frame influenced participant choices for Option A or B. Upon further analysis, we concluded that the Proving Ground frame didn't unduly influence participant choices. For more details on this analysis, please refer to Box D.1 in Appendix D.

- **Participants successfully navigated and were able to effectively incorporate scientific and technical details into their discussions and option selection considerations.** Selections of dialog from the table observation data in the form of vignettes provide examples of a high level of engagement with the technical details of the ARM mission options.
- **Several potential design and recruitment factors may be correlated with the individual and group selection of Option A or B.** Review of the design and recruitment factors of influences ranging from participant demographics to table facilitation show potential correlations that require further analysis.

5.4.1 Common Participant Rationales: ARM A vs. B

The qualitative data from the ARM session is best seen as a way to examine patterns among the reasons that groups and individuals voted for one option or the other. Several dominant rationale themes in participant reasoning emerged (Table 5.4, see Appendix D for detailed analysis).[39]

Table 5.4 – A summary of common rationales used by participants to make their choice for Option A or B.

Level of complexity ARM options were measured along participant perception of the relative level of difficulty in terms of the complexity of the mission.	**Mitigation** ARM options were measured along participant perception that the strategy supports/tests technologies useful in planetary defense.
Uses/builds on proven technologies ARM options were measured along participant perception that the strategy uses or builds upon proven technologies.	**Control** ARM options were measured along participant perception that the approach gives better control over selection of asteroid type as well as control/flexibility over unknown factors with the mission.
Dual-use technologies ARM options were measured along participant perception that technologies developed are useful in multiple contexts.	**Science** ARM options were measured along participant perception that strategy supports research, experimentation, and learning new things.

The way people discuss specific topics associated with the "Informing NASA's Asteroid Initiative" forum tells us a lot about how the Proving Ground frame limits the interpretation of the results. Of course any frame influences how people think about a topic, but people also do not always think narrowly within the frame when they first encounter the issue. Based upon an analysis of common themes, Table 5.5 lists the recurring motivations and rationales that citizens wrote as the basis for their decisions. These results can be read as the common rationales that underlay the technical decision to go with either ARM Option A or B. These themes in some cases represent values, such as valuing extensibility to go to Mars, and in other cases represent risks (e.g., rubble). Each of the codes shown below represents our judgment of a recurring theme in the individual results.

Table 5.5 – Commonly used rationales underlying the choice of Option A vs. B: going to Mars, planetary defense, gravity tractor, asteroid sample, mining, or space junk.[40]

[39] Preliminary themes are derived from a review of group and individual voting sheets using thematic coding and also keyword frequency counts from written participant rationales.

Data are derived from word searches of individual participant rationales given on voting sheets collected after the ARM A vs. B session. The items below represent a subsample of some of the more common tangible reasons (along with some less common reasons for comparison) people used to justify A or B. The first three columns represent the number of times an individual response used that particular rationale to justify his/her decision, regardless of whether he/she voted for Option A or B. The final column indicates what percentage of participants that used the rationale voted for which of the options.

Tangible Reason for Choice	**Arizona (n = 97 responses)**	**Boston (n = 86 responses)**	**Combined (n = 183 responses)**	**Response most related to A or B**
Going to Mars	12	19	31	B = 100%
Gravity Tractor	12	12	24	B = 100%
Planetary Defense	11	10	21	B = 95.2%
Asteroid Sample	14	4	18	A = 61.1%
Mining	8	7	15	B= 66.7%
Collecting Space Junk/Debris	7	1	8	A = 75%
Rubble	1	2	3	B=100%

In general, participants' reasons for choosing A or B varied considerably. Some of the more common reasons related to their interest in Option B were planetary defense (21 mentions) and gravity tractor technology (24 mentions), the latter of which was generally linked to improving planetary defense. **Also, many people related the choice for Option B in terms of going to Mars (31 mentions).** People that chose Option A gave reasons related to collecting space junk (8 mentions) and collecting asteroid samples (15 mentions). In essence, individuals' reasons for choosing between Option A and Option B were varied and quite particular. People may have been biased by their own particular concerns. For instance, those who chose Option B also perceived this technology as being more in line with planetary defense, which was dealt with extensively earlier in the day; thus during the day, it might have become a more immediate concern. Others may have been looking at this through their desire to see economic gains come out of these ventures (e.g., mining), while others were driven by aspirations to explore (e.g., going to Mars), or concerns about the increasing amounts of space junk in Earth's orbit.

A specific example of how an earlier session possibly influenced participants' discussions on ARM Options A and B is their gravitation toward planetary defense as a high future priority for NASA. **There is strong evidence that participants integrated knowledge gained about planetary defense into their deliberations during the ARM session (see Table 5.6 and Table Observation Vignettes).** Additionally, the pre- and post-forum survey results suggest that one of the bigger educational impacts of the event was increased knowledge about planetary defense issues. All three items related to this topic showed statistically significant[41] dramatic shifts towards increased knowledge in this area (see Table 5.6 below).

[40] Going to Mars implied extensibility of the mission to future Mars missions. Gravity tractor referred to an option being better able to demonstrate gravity tractor technology. Planetary defense indicated that the participant thought the option was better for planetary defense. Asteroid sample indicated an appreciation for having a larger sample size, either for research or economic reasons. Mining reflecting a preference for the economic benefits of getting multiple asteroids. Collecting space junk referred to a dual use benefit of Option A—that it could help retrieve junk debris (e.g., old satellites) that is left in space.
[41] Paired T-test, $p<0.01$.

Table 5.6 – A comparison of the average responses on a scale of 1-7 (Absolutely agree = 1; Absolutely disagree = 7) of participants in both Massachusetts and Arizona to the following prompt in the pre- forum survey (n=189) and post-forum survey (n=182): "How would you assess your personal interest and knowledge regarding the topic of asteroids and NASA's future initiatives after participating in this event?" All means are statically significantly different (paired T-test, p<0.01). *Note: Standard deviations are reported in parentheses.*

STATEMENTS ABOUT INTEREST AND KNOWLEDGE	MEAN RESPONSES PRE-SURVEY	MEAN RESPONSES POST-SURVEY
I AM AWARE THAT ASTEROIDS THAT ARE 30-50 METERS ACROSS, WHICH CAN CREATE ABOUT A 1 KM CRATER, HITS EARTH ON AVERAGE EVERY 1,000 YEARS.	3.62 (2.12)	2.03 (1.52)
I AM AWARE THAT THERE IS AN INTERNATIONAL NEAR EARTH OBJECT DETECTION NETWORK IN PLACE AROUND THE GLOBE.	3.14 (2.09)	1.73 (1.19)
I KNOW ABOUT THE METEOR STRIKE THAT OCCURRED IN CHELYABINSK, RUSSIA IN FEBRUARY 2013.	2.49 (2.09)	1.23 (0.75)

Overall, this data suggests that the event helped inform people about asteroid mitigation and detection. This in turn may have influenced the way people saw planetary defense as a high priority (Table 2 in "Draft Interim Report"). This trend is also prominent in the individual rationales for choosing ARM Option A or Option B. Planetary defense, along with the role that gravity tractor technology would play in planetary defense, was one of the most common reasons given for selecting Option B (see Table 5.4).

5.4.2 Tracing the Citizen Rationale

Additional research questions could be asked about the nature of the citizen input. Is it possible to trace why citizens provided the answers they did? Is it possible to see if their input is based on solid and adequate reasoning?

In the text box, the written notes from an ECAST table observer from a Phoenix table that voted for Option A are highlighted for selective benefit. It's clear that the participants carefully examined and read through the data. Some of the terminology provided in the background material caused comment, such as the phrase "challenge," which is commonly viewed inside NASA as a comment that it will be difficult to do analysis. The vignette helps establish that the group made a technically credible decision. Further, the written rationale in favor of A (shown in Table 5.7) listed more mass and potential side benefits of removing space debris. Individual votes provide more clarity on why it was chosen—research benefits were listed and debris removal was reemphasized.

Looking at each of the ballots, it does appear that individuals echoed common themes from the group vote. The issues noted in the vignette by the table observer do not overlap closely with the written rationale, primarily because the table observer focused on how certain risks and concerns with Option A were removed overall. There is an interesting diversity in the individual responses, with two individuals citing cost and schedule and probability instead of size and dual use.[42]

[42] Two additional lines of analysis could be pursued. First, as the text box shows, a few people voiced support for Option A early on, and this perception seemed to carry through the conversation. To what extent is path dependence in conversation, with early advocates having disproportionate influence, a likely influence on the result? The two lengthy responses in the data table may likely be the voices that initially supported Option A. Second, there could be

Vignette 1 (ECAST Table Observer Notes from a Phoenix table that voted for Option A) – At one of the four tables in Tempe that voted for Option A, several participants expressed their preference for "the bag" very early in the conversation. A great deal of attention was given to sorting through technical questions, most of which the participants resolved by consulting the background material and table cards. This group questioned the material that had been provided to them and they also questioned one another. Given the concerns in the video that the material to be retrieved via Option A might turn out to be a rubble pile, **the group asked the NASA experts if this affected the value of the material. The response was that "There is nothing wrong with capturing a rubble pile.** The astronauts would still be able to approach the captured rubble pile, so the crewed mission could still work either way. The composition of the asteroid could be more or less interesting for science." This reinforced the participants' views that there were few downsides to Option A. As one participant noted upon receiving the expert response, **"*Well if they don't know the value of it then it's not a risk.*"** The conversation then turned to the nature of the risk described in the background material, with one participant noting that "*it says there is a possibility the asteroid would have to be de-spinned, and engineers don't know how to figure that one out*," but another immediately respond that "*it said it was more of an engineering challenge*" and went on to argue that **she took this to mean that it was a challenge that could likely be overcome**. This attention to detail and shared problem-solving was evident throughout the discussion. While there were some disagreements between participants on particular facts and arguments, and both pros and cons of Option B were discussed, all participants readily expressed their support for Option A when the facilitator polled them.

Table 5.7 - Combined Group and Individual Written justifications for the table discussed in the text box.

Table/Participant	Option A	Option B	Most Important Factors/Primary Motivation
4	1		Scenario A More material, space junk, side benefits
4-1	1		Seems more probably
4-2	1		It can pick up space junk as well as asteroids. It can get bigger asteroids, too.
4-3		1	Cost and safety
4-4	1		Get a whole asteroid rather than a small piece of one. Practical application of also collecting space trash in orbit around Earth.
4-5	1		Larger sample for more research
4-6	1		Scenario A allows us to take a larger sample of the asteroids. A single boulder may not be indicative of the materials and properties of its host asteroid. An entire one lets us have a larger sample until we have a more focused research goal.
4-7	1		Smaller boulder in option 2 can be from another boulder and not necessarily able to give us the info for the "big 1". Also, love the idea of "cleaning" up the solar system.

questions about the concept of "boundary objects" as relates to the decision here. While the table was able to agree on Option A, it's clear that individuals had subtly different reasons for embracing it, and one person even disagreed.

5.4.3 Technical Complexity in the Table Discussions

One way to judge the utility of the deliberation in providing space for the development and expression of informed views by members of the public is to directly observe the conversations among participants.[43] If one can observe at a table discussion over the course of a day that participants drift among topics or simply cannot understand important technical issues sufficiently for forming an opinion about them, the utility of the deliberation clearly is called into question. On the other hand, if the participants engage with the complexity of the issues and provide a clear rationale for their views, they have attained a level of informed and considered insight that rarely characterizes public opinion about policy issues. For the asteroid deliberations in Tempe and Boston, researchers observed the full day of discussion at 8 of the 27 tables that were convened at the two sites. The table observations aimed to provide data that could shed light on two questions:

- What was the quality of the deliberation?
- What reasoning did the participants use in developing and expressing their views on the questions put to them in the course of the day?

An analysis of the data from 4 tables provides considerable evidence that the quality of the discussions was high in many fundamental regards. At all of the tables reviewed here, all or most of the participants contributed their thoughts; most or all of the issues and arguments raised in the background materials and videos were considered by the participants; while some participants spoke more than others, there were no instances in which one or two dominated the discussion (even at one table that included a master's and a Ph.D. student in astrophysics); there were few uncorrected errors or misconceptions in the discussions; and the reasons that participants provided individually and as groups for their votes were consistent with those addressed in discussions. In addition, the table observations showed that many participants considered and in some cases advocated reasons in support of their views on Option A or Option B that were not reported with the votes. Nonetheless, there was variation in the extent to which participants identified issues not addressed in the background material, in how directly they engaged one another's arguments, and how well they understood the material.

To further explore the quality of deliberation, we provide vignettes from 4 tables that provide some insight into the common features and variety of the discussions: one that supported Option A (see Vignette One quoted above); two tables that supported Option B and one that was split over A vs. B are quoted below. **There are some challenges in conversation, but on the whole we feel that the deliberation reflected strong and thoughtful communication among citizens.**

[43] Chilvers, Jason (2008). "Deliberating Competence: Theoretical and Practitioner Perspectives on Effective Participatory Appraisal Practice." *Science, Technology and Human Value* 33(2): 155-185; Stirling, Andy, (2008). "'Opening Up' and "Closing Down': Power, Participation, and Pluralism in the Social Appraisal of Technology." *Science, Technology and Human Values* 33: 262-294.

Vignette 2 – One of the tables supporting Option B in Phoenix had a less focused conversation than the one reported in Vignette 1, and did not raise questions about the background material. Thus, even though the question about the value of rubble discussed in Vignette 1 had been projected on the screen at the front of the room, one participant equated rubble with low value by saying "*I think that B would be better only because if we're paying all this money for a mission and we do A and it just happens to be a bunch of rubble, it's useless and we just wasted a bunch of money.*" No one contested this view. While all participants except one were active in the conversation, their comments often did not engage those of others in the group. For example, while one was picking up an earlier thread in the conversation, another interrupted to reiterate an earlier claim that the cards seem biased: "*NASA wants us to select B*." A third then added the comment that Option A might take longer to retrieve due to the mass of the target object. In the end the participants provided four clear reasons for preferring Option B, but the means by which thev arrived at this conclusion were less clear than at other tables.

Vignette 3 – Participants at this table in Boston were fairly methodical in discussing Option A vs. Option B and in arriving at their unanimous decision. The facilitator pressed them for their rationales and there was much discussion but little disagreement among people. Several technical issues were sorted out among the participants, such as the challenges of retrieving a boulder, how to select "the right" boulder, and whether what seemed a boulder was instead a part of the main body of the asteroid. Most seemed to agree that Option B was a better fit for the Proving Ground because it applied more to getting to Mars. All participants contributed fairly evenly except John, who did not speak, and Lisa, who was asked for many clarifications because she consistently looked through the background information and expert Q&A transcript from Arizona for answers to the questions that had been asked by the participants there. In general, this group stuck to the information provided them except for mention of the probe landing on the comet in the week before the Boston event, which they likened to Option B.

Vignette 4 – Several people expressed that the small boulder option was "boring"; in general there was an impulse to go for the biggest, most impressive choice, despite taking note of cost and technical impediments to success. The group was less focused than before lunch. The conversation was between Barbara and the rest of the table. Her responses made it clear that she did not understand what they were saying. Her confrontational tone and refusal to admit that she did not understand frustrated the other table members, and the atmosphere at the table was tense. They were unable to come to an agreement. They did agree, however, that the questions were unclear. One person said the first question regarding the Proving Ground was a leading question; some background materials had specified that the boulder-grabbing option was better for preparing for Mars, which seemed to be the point of the Proving Ground strategy. Frustrated with what they saw as vague definitions and several contradictory and unclear sections of background material, Samantha said that this section was "*poorly presented*."

6.0 Mission Planning and the Journey to Mars

6.1 Background and Topic Overview

The Asteroid Initiative, and in particular the Asteroid Redirect Mission (ARM), is part of NASA's broader human space exploration strategy. ARM, if implemented, can satisfy a variety of technology development goals needed for exploration, such as solar electric propulsion and deep space extra vehicular activity techniques that are needed for many different exploration missions. When ECAST content developers engaged NASA on what issues it wanted public input on, NASA experts talked about its exploration mission planning process, including how to plan future missions after ARM.

This session was thus designed to focus on how NASA might plan missions after ARM. NASA has recently begun a broad strategic and communications effort aimed at describing a "Journey to Mars," and Mars has increasingly become prominent as the horizon goal for exploration. This session on the Journey to Mars is by no means meant to reflect an assessment of the Journey to Mars campaign. Rather, it reflects an attempt by us to explore questions that NASA managers are considering for deep space exploration, of which ARM and the Journey to Mars mission are integral and connected parts.

This session was specifically framed to assess one key mission planning approach that NASA has discussed with ECAST, the capability-driven framework (CDF). The CDF focuses on incremental planning steps and making decisions that could support multiple possible missions.[44] Because ARM is able to prove capabilities for future, farther missions into deep space, NASA believes it is a strong example of this framework. **Participants were told that the capability-driven framework is a departure from the traditional space mission-planning model. Instead of selecting a destination—like the moon or the International Space Station—and developing the techniques and technologies needed to achieve that goal, this approach develops the capabilities to travel to a range of deep-space destinations. As these vehicles and capabilities mature, increasingly complex missions can be selected to destinations farther out in the solar system.** Missions would be funded, designed, and carried out as NASA's budget, capabilities, and partnership opportunities dictate. Rather than a detailed start-to-end plan, such as the Apollo Program had for lunar exploration in the 1960s, this approach does not need final, fixed goals in place before initial missions are carried out. This method has the potential to be more efficient and cost-effective, as the path towards the eventual goal of Mars exploration is flexible. Technologies can be developed, tested, and refined in a lower-risk environment than, for example, an immediate crewed mission to Mars, which is commonly seen as the ultimate goal of NASA's human exploration efforts.

While participants had the CDF concept described for them, the session needed to make the CDF concept relatable to a broad audience that had varying levels of education. **To appeal to a broad audience, ECAST defined Proving Ground as effectively entailing the CDF.[45]** Merriam-Webster defines "proving ground" as a place where things or people are tested or tried out for the first time; a place where scientific testing is done. NASA refers to the "Proving Ground" as a phase of human and

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[44] For example, see: http://www.nasa.gov/sites/default/files/files/20140623-Crusan-NAC-Final.pdf.

[45] NASA does not define Proving Ground in terms of the capability-driven framework. ECAST made this connection for deliberation purposes, being concerned that the phrase "capability-driven framework" would be difficult to discuss with a diverse audience composed of differing education levels. Proving Ground was easier to say and seemed to convey the intent of the CDF. Both concepts were introduced in the background material, and were tied to one another: see the appendix for the official information. We will discuss later whether there was possible confusion between "CDF" and "Proving Ground," but our analysis shows that the public did seem to accept the two terms as being related.

robotic missions that prepare for and prove our ability to safely live and work away from Earth for extended periods of time. The proving ground was defined to the participants as centralized in cis-lunar space (between the Earth and moon), but encompassed activities conducted aboard the International Space Station, and robotic missions on and around the moon, Mars, and farther into the cosmos. NASA's capabilities would continue to mature through missions in the Proving Ground, leading to the ability to go to Mars. As such, the Proving Ground and CDF were conceptually related, as the final destination and mission concept for human exploration is not defined for the Proving Ground beyond the initial missions.

The Journey to Mars is seen as the mid-21st century goal for NASA's human exploration efforts, effectively putting a goal behind its Proving Ground efforts. Participants were asked if they wanted a more detailed exploration plan. Indeed, the end of the Journey to Mars video asked citizens: "However, the main part of the discussion will focus on the more immediate future, and how the plan for Mars should be laid out as we move forward. Would you like to see an entire strategy laid out now, or are you comfortable with a series of Proving Ground missions (such as the Asteroid Redirect Mission) that are undertaken as budgets and capabilities dictate?" This question effectively tied the Proving Ground and CDF concepts together. **Participants were later asked whether they accepted the Proving Ground framework, with this question serving as a proxy for whether they accepted the capability-driven framework.**

ECAST wanted to provide further contrasts for the public to deliberate on, to draw out some of their preferences on mission planning for Mars. There are many challenges involved in going to Mars, several of which were discussed with participants (Appendix G, Section 4). The bulk of the Journey to Mars background material discussed three different scenarios for the exploration of Mars. Each of them assumed that multiple Proving Ground missions had been performed, advancing humanity's exploration capabilities to a higher level than exists today. The context for discussing these scenarios was: what missions should follow the Proving Ground missions? We selected three notional scenarios in order to help describe a range of potential mission types for exploring Mars: 1) a robotic and crewed orbital scenario, 2) a "Viking" scenario (several-month crewed mission with first return opportunity back to Earth),[46] and 3) a "Pioneer" scenario (establishing a permanent settlement) (see Box 6.1 for definitions). These three scenarios were not NASA concepts, but were proxies used by ECAST to make the range of mission scenarios more understandable to the forum participants.

[46] "Viking" here refers to the historical Vikings of northern Europe, who visited North America before Columbus but did not establish a permanent presence. The "Pioneer" label for the third scenario was the phrase used by ECAST to describe the notion of a permanent settlement on Mars. NASA has separately used the phrase "Pioneering Space" to describe a set of principles for exploration, but this was not discussed or intended to be part of the discussion during the forum. For reference to NASA's discussion, see http://www.nasa.gov/sites/default/files/files/20140623-Crusan-NAC-Final.pdf.

Box 6.1 – Three mission scenarios for Mars following the Proving Ground were presented to participants during the "Journey to Mars" session. For further details, consult background

Robotic and Orbital/Moon Mission Scenario: This scenario, which entails a crewed ship orbiting Mars and potentially visiting the Mars moons (Phobos and Deimos), involves a much larger array of robotic explorers being sent to Mars than NASA currently has. While this option does not involve a crewed landing on the surface of Mars, the astronauts in orbit would be able to remotely operate robots on the surface in a much more efficient and directed manner than teams on Earth. Since this is the least intensive option in terms of scale, it is also the least expensive and involves the smallest amount of risk. Without the need for human-rated landing and ascent vehicles, the amount of research and engineering that would need to be undertaken is a fraction of a mission involving a crewed landing, lowering cost and making this scenario possible on a fairly short timescale. The absence of setting humans on the surface of Mars results in a substantial reduction in the risk to the astronauts in many respects. This option also may be less exciting to the public than human footprints on the surface.

Viking Scenario: This scenario involves a small-scale crewed exploration mission that puts humans on the surface of Mars to live and work for several months before returning to Earth. Up to six astronauts would be selected to make the journey, and it would be launched at a time that would provide for not only a short travel time but also the shortest possible stay on the surface to minimize risk to the astronauts. Having astronauts on the surface of Mars would greatly increase the relevance and amount of science data that the mission would yield compared to remote operation of robots. However, the technical and engineering hurdles that need to be addressed result in a major cost and timeframe increase. While risk would be minimized, it would still be substantial for all of the astronauts involved. Without a permanent habitation plan, there is the risk that the mission will suffer a fate similar to the Apollo program. That is, once humans accomplish a crewed landing on Mars, interest and support in the Mars program may wane to the point of cancelling any future missions.

Pioneer Scenario: This scenario involves a permanent settlement on the surface of Mars. This settlement would be preceded by a fleet of robotic and supply ships that would deposit food, fuel, and materials on the surface. These robots would also begin preparations for constructing permanent habitats. An initial large crew of human explorers would be refreshed every few months with additional supplies and new personnel. A mission of this scale and duration would be able to unlock a large number of the mysteries concerning the history of Mars and the entire Solar System. Multiple locations could be settled or scouted, offering opportunities for an abundance of diverse scientific research. Mars pioneers would become "Earth-independent," meaning that such a mission might no longer require support from our home planet and may become self-sustaining. The technology and techniques required for such an undertaking would be extremely challenging. Methods of dealing with radiation, extracting water, producing fuel and air, propulsion, habitat construction, and a number of other techniques would need to be vastly improved before this scenario becomes feasible. It would require a greater commitment to human expansion and a colossal increase of cost, risk, and timeframe over the orbital and Viking scenarios.

material given to participants (see Appendix G, Section 4).

Collectively, these three scenarios represent different approaches that NASA could pursue as follow-ons to the Proving Ground, effectively representing ways to implement the CDF. All scenarios involved crew either in Mars' orbit or on the surface of Mars. Each one differed in terms of its cost and schedule complexity, with orbiting crew and robotic missions being the least costly, and quickest to achieve. The Pioneer mission could be the most expensive and, if chosen as the immediate follow-on to the Proving Ground missions, would take the longest amount of time to complete. In general, the implication was that participants choosing more complex options would have to wait longer for interim successes—this is often a constraint that faces real decision makers at NASA. Again, as with the options described in other deliberation sections, participants were told that these options were not mutually exclusive, but tradeoffs on cost and schedule should be considered. Being able to choose between these three options effectively involves asking the public to choose between different levels of programmatic risk, i.e. different levels of risk about cost, schedule, and safety issues. **Asking participants to consider cost and schedule tradeoffs among the scenarios helps them understand the constraints under which NASA operates, which in turn is what motivated NASA to develop the capability-driven framework. The citizen deliberation on cost and schedule constraints thus helped prepare them for the deliberation on the CDF.**

6.2 Session mechanics

This session solicited individual preferences regarding mission-planning strategies for crewed Mars missions. After discussion of the crewed mission, facilitators provided an overview of the three different Mars exploration scenarios (robotic/orbital, Viking, and Pioneer) and the benefits and drawbacks of each. The session closed with a discussion on the merits of the Proving Ground strategy as way of completing one or more of these mission scenarios.

This 60-minute session had four components: a video, discussion of the three exploration scenarios, discussion of the proving ground strategy, and individual responses. The seven-minute kickoff video highlighted the background material participants received prior to the event, reiterating both the challenges involved in going to Mars as well as the three hypothetical Mars exploration strategies.

After the video, participants had 40 minutes to share their reactions to the video and discuss the three exploration scenarios. **Facilitators first steered the conversation toward specific topics such as astronaut safety and scientific benefit, then later shifted the discussion toward considering the cost, risk, and timeframe tradeoffs among the three Mars mission scenarios, and closing the discussion with a focus on the bigger picture: what should our space exploration goals as a society be? Facilitators helped clarify that the scenarios for Mars exploration would occur after the Proving Ground missions were completed.**

Box 6.2 – Individual voting ballot used by participants in the "Journey to Mars" session.

Individual Voting sheet: Mars Exploration

Which mission profile is a better choice for the future of Mars exploration?

_____ Robotic exploration approach: crewed missions to Mars orbit or moons
_____ Viking approach: small-scale missions to the surface of Mars
_____ Pioneer approach: permanent human settlement on the surface of Mars

What were the primary reasons for your choice?

Do you support moving forward with the Proving Ground strategy?

______ Yes, entirely
______ Not quite sure
______ Not at all

What were the primary reasons for your choice?

Lastly, facilitators asked participants to consider the Proving Ground strategy itself, which was described as part of the capability-driven framework. The discussion centered on whether this strategy was satisfying and compelling to each participant in the context of exploring Mars. As the discussion period came to a close, facilitators asked each individual to decide what mission scenario they preferred and whether they were in favor of using a Proving Ground strategy to advance a mission to Mars (see Box 6.2 for sample voting ballot.)

6.3 Results

6.3.1 Participant Preferences for Mission Type

On average, participants at both sites favored the robotic/orbital (robotics on ground with crew in orbit) scenario (48.2%) over the Pioneer (permanent human settlement on Mars) scenario (35.2%) and the Viking (one-time, short-term expedition on Mars) scenario (16.8%) (Figure 6-1).[47] In terms of the provided background material, this means that the public chose an approach that was the lowest cost and quickest to potentially achieve as a primary goal. The most expensive scenario, requiring the most time to complete, was rated as the second choice (Pioneer). Although the crewed orbit and robotic mission scenario was the most popular, there was still a strong preference among participants to actually land people on Mars, as the Viking and Pioneer scenarios together accounted for 52% of the public's preferred mission scenario overall, indicating a nearly 50/50 split in the participants' preference for a crewed orbital mission or a mission that involves astronauts landing on Mars. In the discussion we will more deeply explore reasons why people voted the way that they did, but their choices here likely reflect a mix of individual assessments of the value of the different Mars scenarios combined with an understanding of the cost and schedule results.

When comparing sites, participants in Massachusetts and Arizona diverged in their preferred approaches. People in Massachusetts voted for the robotic/orbital exploration approach (57.3%) at a significantly higher frequency than in Arizona (40.2%).[48] Arizonans preferred to land on Mars (59.8% voted for Viking and Pioneer combined) more than participants in Massachusetts (42.7%).[49]

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[47] Chi-sq. = 6.65, DF=2, p=0.036.

[48] Chi-sq. = 5.70, DF=1, Fisher's exact p=0.021.

[49] Other data, to an extent, corroborates this pattern. In the post survey section, "NASA's Future Plans," participants from Arizona considered deep space exploration and manned missions to Mars a slightly higher priority than participants from Massachusetts on all eight questions. However, these differences were not significantly different (Two-sample T-test, p>0.05.). The largest divergence occurred on questions concerning crewed missions (questions 5-8). Although the differences between Massachusetts and Arizona only indicate a tendency, the important thing to consider for our purposes is the consistency of this tendency across all eight questions. Along similar lines, we found a more pronounced demographic pattern of interest. There was a relatively large divergence on this issue between males and females. Males consistently indicated deep space exploration as a higher priority than women (third and fourth columns, Table 6.1). This suggests that gender could prove to be an important demographic factor to understand in relation to deep space exploration.

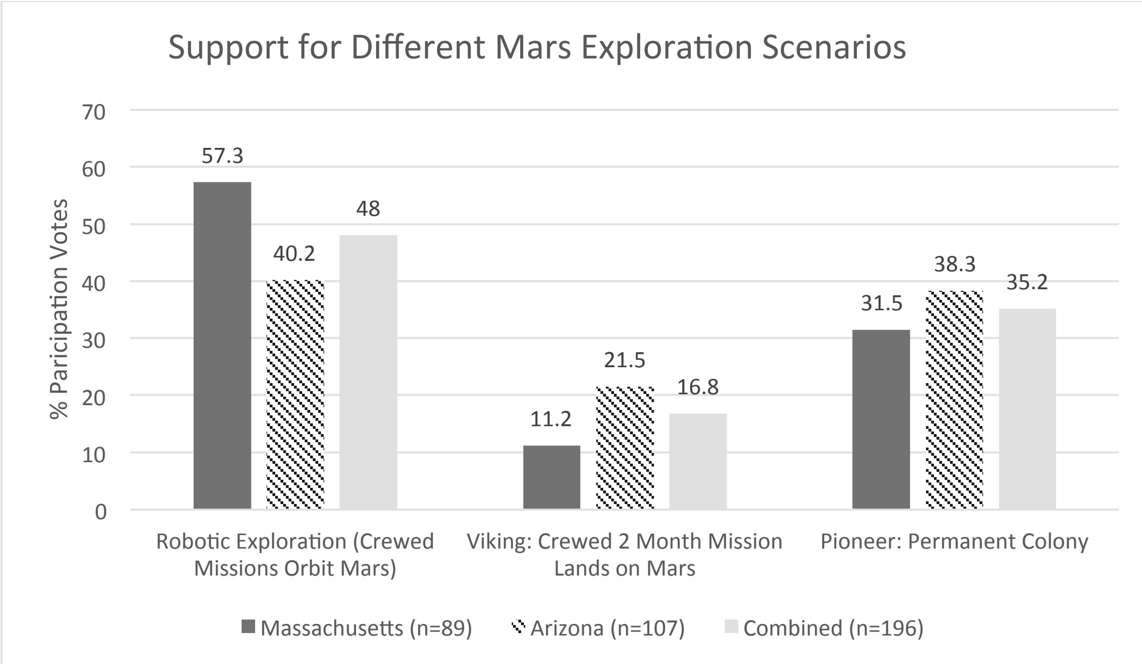

Figure 6.1 – Percentage of participants that voted for each of the Mars exploration scenarios in Massachusetts (n=89), Arizona (n=107), and both sites combined (n=196).[50]

Table 6.2 shows results from a different set of questions asked of participants in the post-forum survey, but which wasn't a dedicated part of the deliberations. NASA has been talking about expanding its capabilities going beyond the International Space Station, including future missions to the space beyond the moon (cis-lunar space) and on to Mars. These questions asked participants to express their priority for achieving these exploration milestones at two different time-scales: 10 years and 50 years. These data are unique and care must be taken to not extrapolate too much from it.

In general, the highest priority was given to the most attainable milestones: i.e., going beyond the International Space Station has the highest priority across all of the goals, and going to the surface of Mars has the lowest priority. In all cases, the 50-year time horizon results were given a higher prioritization than the 10-year results. ECAST does not yet have an opinion about how to assess the absolute priority given to the Mars goal: that is to say, what does the 4.51 combined ranking across MA/AZ for a permanent presence on Mars in 50 years mean? Assessing tradeoffs contrasting these goals to other public concerns would be a valuable subject for future research. The results also seems to show a slightly higher priority for the exploration goals in Arizona than in Massachusetts, and the differences between men and women in the results is also worthy of future study.

[50] The higher N for this analysis is the result of some participants voting for more than one scenario. Although the voting ballot asked participants to choose what they thought was "the better choice," (see Box 6.2) some chose more than one anyway. It is hard to know whether this was deliberate or a misunderstanding of the prompt. Regardless, we felt the data was indicative of participant preferences, so included all choices in this figure.

Table 6-2 – The average responses on a scale of 1-7 (Not a priority = 1, Neutral = 4, Highest priority = 7) of participants in Arizona (n=96), Massachusetts (n=86), Males (n=90), Females (n=90), and Massachusetts and Arizona combined (n=182) to the following prompt in the post survey: "Please assess what you believe should be the most important short-term and long-term priorities of NASA." Note: Standard deviations are reported in parentheses.

Potential NASA Planning Priorities	***Arizona***	***Massachusetts***	***Male AZ/MA***	***Female AZ/MA***	***MA/AZ Combined***
(1) In the next 10 years, how important is it for humans to travel beyond the International Space Station?	4.97 (1.90)	4.67 (1.77)	5.02 (1.86)	4.64 (1.82)	4.82 (1.84)
(2) In the next 50 years, how important is it for humans to travel beyond the International Space Station?	5.56 (2.03)	5.25 (1.92)	5.66 (1.96)	5.22 (1.94)	5.42 (1.98)
(3) In the next 10 years, how important is it for a human-crewed mission to orbit Mars or one of Mars' moons?	4.55 (1.93)	4.21 (1.70)	4.64 (1.87)	4.14 (1.77)	4.39 (1.82)
(4) In the next 50 years, how important is it for a human-crewed mission to orbit Mars or one of Mars' moons?	5.37 (1.97)	5.13 (1.91)	5.58 (1.83)	4.94 (2.00)	5.26 (1.93)
(5) In the next 10 years, how important is it for humans to step foot on Mars?	4.10 (2.04)	3.65 (1.84)	4.19 (2.07)	3.58 (1.79)	3.88 (1.95)
(6) In the next 50 years, how important is it for humans to step foot on Mars?	5.23 (2.10)	4.65 (2.11)	5.30 (2.04)	4.61 (2.16)	4.96 (2.12)
(7) In the next 10 years, how important is it for humans to establish a permanent presence on Mars?	3.80 (2.17)	3.35 (1.93)	3.97 (2.09)	3.20 (1.98)	3.58 (2.06)
(8) In the next 50 years, how important is it for humans to establish a permanent presence on Mars?	4.68 (2.27)	4.32 (2.12)	4.94 (2.07)	4.08 (2.25)	4.51 (2.19)

6.3.2 Results of the Proving Ground Strategy

As discussed above, participants deliberated on the Proving Ground strategy, which was defined in relationship to the capability-driven framework. **A majority of people at both sites (67.9%, Figure 6.2) supported moving forward with the Proving Ground strategy**.[1] Very few people voted against the Proving Ground strategy: 7.2% of Arizonans and 1 person in Massachusetts. All the no votes in Arizona can be accounted for at two tables, where these participants consistently went against the grain in previous sessions. **However, a significant number of people at both sites were "unsure" (27.7%) that they would support moving forward with the Proving Ground strategy.**

As has been stated earlier in the report, caution should be taken against extrapolating too much from these results**. They may suggest that the public, if given an opportunity to learn about the constraints that NASA is operating under, may accept the capability-driven framework.** The later discussion of written rationales will explore why people chose different results. The background material had asked participants if they wanted a fully laid-out plan to Mars now, and this answer seems to imply that they may be accepting of a) incremental, b) multi-purpose missions that c) react to budget constraints. We have done a separate analysis, elaborated on in the discussion, that shows the extent to which participant responses embodied these aspects of CDF. The majority of respondents directly addressed core aspects of CDF in their written results, which enhances the credibility of this result.

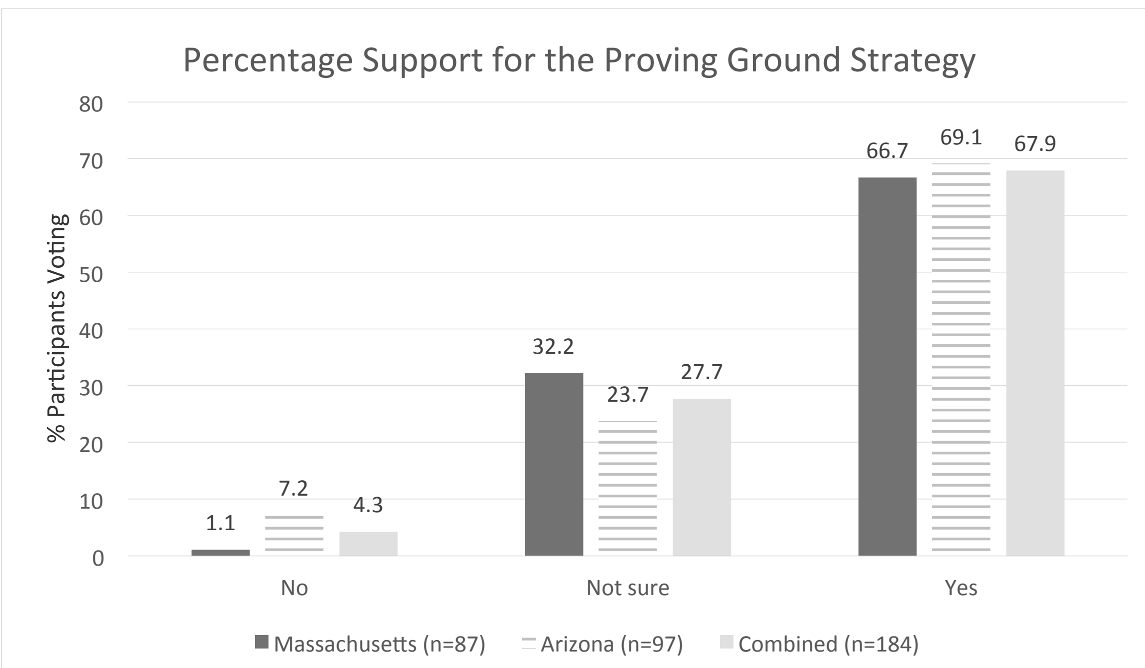

Figure 6.2 – Percentage of participants voting on whether they support moving forward with the Proving Ground strategy in Massachusetts (n=87), Arizona (n=97), and both sites combined (n=184).

[1] Chi-sq. = 28.78, DF=2, p<0.0001.

6.4 Discussion

6.4.1 Public Value Mapping of Mars Exploration Scenarios

One of the primary values of deliberations is that you can go beyond quantitative polling results and dig deeper into the diversity of values that the public holds concerning a particular issue. For instance, what is the diversity of ways the public will perceive a mission to Mars? And how do these values align with NASA's goals? The above discussion of Mars exploration scenarios requires citizens to think about the value of different missions to Mars, ranging from crewed orbital missions alongside robotic missions, a quick sortie to Mars (Viking), and a push for a permanent presence on Mars (Pioneer). Each individual may have a different perspective on the importance of crew in orbit as opposed to having robots or people on the ground. They also may have opinions about how soon they would like to see activity occur at Mars. Once participants learned what each of these mission scenarios entailed, they were asked to vote for their preference and explain why they preferred the mission type they voted for. Below we map out the values that participants expressed in relation to each of the proposed mission types. Table 6.3 provides a summary of the main rationales that emerged from deliberations concerning each of the three mission scenarios, which in many ways reflect some of the values that the public holds with respect to exploration. While we will not discuss it in detail, it should be noted that differences existed in the values mentioned at each site. For further analysis on differences between Arizona and Massachusetts, see Box E.1 in Appendix E.

Table 6.3 – Rationales underlying Mars scenario choices: *ECAST reviewed the written rationales participants wrote for all responses and scenario votes and synthesized them into the most common categories. The most common rationales that emerged during deliberations are described below. ECAST found that proponents of an individual scenario tended to elicit similar values that were different than voters for the other two categories. Note: The numbers in parentheses are the percentage of participants that voted for each of the mission types (Arizona and Massachusetts combined – see also Figure 6-1).*

Robotic/crewed orbital missions (48.0%)	**Viking – 2-month manned mission (16.8%)**	**Pioneer – permanent settlement (35.2%)**
Economic feasibility (lowest cost)	Human research better than robots	Human ambition
Practical next step to humans landing on Mars	Middle ground: leads to permanent settlement	Multi-planet species goal
Minimizing risk	Middle ground: helps decide if we should have permanent settlement	Generate public interest
Benefits of research	Robotic research has already been done	Advance science and technology
Fastest milestone	Preparation in case catastrophe on Earth	

Robotic and Crewed Orbital Missions: Four main rationales emerged from the deliberations for those who chose crewed robotic and crewed orbital missions as their preferred strategy for exploring Mars: 1) economic feasibility; 2) practical next step to exploration; 3) minimizing risk; and 4) the benefits of research. Participants also developed a number of less common rationales related to the ethics of carrying out missions that land people on Mars. For instance, one participant explained that she preferred robotic missions because *"I am unsure of the moral and ethical validity of creating inter-planetary colonies."* Another questioned the value of people settling Mars when problems on Earth are so extensive:

> *"I agree space and Mars exploration is important, especially for encouraging and fostering the drive of scientific advancement and scientific creativity, but I feel it is selfish to consider further exploration when there are so many issues and concerns present that are so pressing and urgent in our world."*

And there were some people who had trouble seeing the value of settling Mars when there is no evidence of life on Mars.

However, the majority of participant responses fell into the four main rationales identified above. In terms of economic value, many participants believed the cost of robotic missions would be less than having manned missions land on Mars—that they would be "*Cheaper to implement and could be done in a shorter time frame,"* or it would be the more *"fiscally responsible option. The engineering required to send infrastructure for other options seems unfeasible."* But as the latter quote illustrates, many of the economic rationales were also tied to practical technical concerns, minimizing risk, and setting the stage for manned missions. The participant quote below illustrates the way people synthesized values during discussions:

> *"Budgetary reasons, human liability, and the technology (current) will limit a long term future of Mars exploration. I believe the robotic exploration will be a better choice when allocating funds to explore the planet (Mars) and get a better understanding of how to permanently settle a colony."*

Therefore, many of the participants who chose this mission type were seeing it as a practical next step—that crewed robotics missions conducted from Deimos or in Mars' orbit could "*generate interest and set the stage for a pioneer approach. Crew[s] can conduct tests on the moons/in orbit that build towards landing on the surface."* In essence, the value of *"robotic exploration with a manned control in a nearby moon could set the precedent and build the scenario for the implementation of a future Mars human settlement."* And along with economic considerations, minimizing risk was a high priority: *"We should start out with the mission that has minimal risk and slowly move up to more dangerous missions so that we have more knowledge."* **In sum, most people who chose the robotic/orbital option weren't excluding the possibility of crewed landings on Mars, but saw robotics missions with crew in orbit as part of a natural progression that would achieve an earlier milestone, minimize risk and cost, and increase scientific knowledge prior to taking on more costly missions to Mars.**

Viking Approach: The Viking approach was the least popular choice among participants. There are two main reasons why this may have occurred, which may reflect the "personalities" of the people that chose either the robotic/orbital scenario or the Pioneer scenario. As we pointed out in the last section, many people chose the robotic/orbital scenario because they saw this as a logical first step in a progression toward shorter crewed missions to Mars, then permanent settlement. So for those people, the Viking scenario was not problematic per se, but we are not ready for it yet. Participants who chose the Pioneer scenario were focused on more ambitious goals and felt that framing a mission around permanent settlement would garner more public support (see next section**). The Viking approach, then, may have fallen victim to the more pragmatic sentiment associated with the robotic/orbital scenario and the perception that permanent settlement of Mars was more exciting and worthwhile than simply getting boots on the ground.** As several of the people who chose the Viking scenario expressed, it was more of a “middle-ground” approach.

It is worth noting, however, that participants who chose the Viking approach formed their own set of unique rationales to support their decisions. Many participants who chose the Viking approach saw it as a feasible middle ground: *“We already have robots, and a colony is incredibly unrealistic.”* In this case, the Viking approach was seen as pushing the envelope, going beyond what we already know how to do. Others thought the Viking approach would result in better research than robotics missions guided by a crew in Mars’s orbit: *“If astronauts physically went to Mars, it would answer more questions.”* Along these lines, another participant felt that the robotic/orbital and Viking scenarios might be redundant, so the Viking approach had more value because *“Vikings will have to use robots anyway and gives us better samples and information pertinent to deciding if a human settlement is even possible.”*

Also associated with the middle-ground theme, a few participants saw the Viking approach as a stepping-stone that gives us options in case bad things happen on Earth. For instance, as two different participants wrote:

> *“Use the Viking approach as a potential base/catalyst for pioneer further down the road. Viking can act like the ISS, and will encourage important tech. advances that may help for survival on Earth as it changes (natural/manmade global warming, pollution, resources, etc.).”*
>
> *“It's an acceptable middle-ground. The trips to the surface would require advanced technologies; they, in turn, would make the pioneer approach possible if conditions on Earth require.”*

In sum, participants who chose the Viking scenario formed rationales related to middle-ground approaches that would take us beyond robotics so that we could *“advance technologies”* and produce better research that relies more on human perceptions. In this regard, many people who chose the Viking scenario saw research using robots as an intermediate step, with the robotics/orbital scenario being limited relative to what humans could do in person. Several of these rationales also saw the Viking scenario, because we had already done so much robotic research, as the first logical step toward more permanent settlements on Mars, while others saw it as a logical step to determine whether humans should establish permanent settlements on Mars. We should note, however, that there may have been some confusion among participants about whether the orbital/robotics scenario involved crewed missions, which could complicate the analysis of these results. A small number of written rationales suggested that some participants didn’t understand that the orbital/robotics scenario involved crewed missions. As a result, some people might have chosen the Viking mission because *“we already have robots.”* If this is the case, then one could surmise that the number of people preferring the orbital/robotic scenario is an underestimate.

Pioneer (Permanent Settlement on Mars): Five rationales stand out among people who voted for the Pioneer scenario: 1) human ambitions; 2) making humanity a multi-planet species; 3) public interest; 4) scientific research; and 5) advancing technology. Much like with the other scenarios, many of these values were intertwined in single statements. However, **unlike the robotic/orbital and Viking scenarios, economic, risk, and technical practicalities were downplayed considerably in the rationales of participants wedding themselves to the Pioneer approach**. **Either cost concerns weren’t mentioned, the costs of other mission types were considered a waste of resources, the**

costs were mentioned but subjugated to the need for ambitious goals, or costs were couched in terms of being a long-term investment that would eventually pay off. For the latter justification, one participant suggested that "*a colony has multiple future uses that justifies the extreme cost."* Several participants also saw the other missions as a waste of money and solely tied to national pride: *"The possibility that we might go to Mars and then leave like the Apollo missions seems unacceptable to me. It just ends up being a waste of resources and is reduced to nationalistic pride."* However, the way most participants approached cost in this context can be captured in this quote: *"So much innovation and discoveries waiting to be made! Incredibly expensive and ambitious, but in encapsulates the human spirit."*

As this previous quote stated, many participants who chose the Pioneer scenario were focused on achievement. We as humans should "*Go big or stay home,*" as one participant put it. Or as another participant opined, the "*penultimate goal of humans [is] to spread to other worlds*." This ambition was highly related to making humans a *"two-planet species*." Becoming a multi-planet species was important for several reasons along these lines. For instance, some participants simply saw it as a way of advancing frontiers: *"Earth independence. Advancing our proving ground farther so that we may move our frontier even further out!"* However, others tied this imperative to increasing the likelihood that humans would have a long-term viability in the universe; in one person's words, *"not have all eggs (humans) in one basket (Earth)."* As with the Viking scenario, participants' concerns about potential "*catastrophe*" on Earth made the Pioneer approach attractive because it would "*ensure that a catastrophic event on Earth would not spell the end of humanity*."

Scientific and technological advancement was also tied to permanent settlement. Some participants perceived large-scale, ambitious projects as a driver of technological innovation. In essence, making the settlement of Mars a priority would be *"awesome! Make the solar system seem smaller, get human eyeballs seeing Mars and science excitement, future social impact and technological advances will follow."* The inherent complexity of such a mission would necessarily cause technology to improve.[52]

Many participants felt that a couching Mars exploration in terms of permanent settlement would maintain public interest, thus helping to sustain the political capital needed to pull off such a mission. One participant was concerned that *"the Viking approach may lead to the same disinterest that followed landing on and then leaving the moon."* Instead, as one participant put it, *"Go big or have everyone lose interest really fast - this should be done after lunar landing and would serve as good practice for exo-planet colonization."* Along those lines, another participant felt the big splash of settling Mars would have a better chance of bringing *"public awareness to space."*

Overall, like with the other mission types, participants perceived the value of a Pioneer scenario in a diversity of ways. It is interesting to note that while doing this that some didn't dismiss the orbital/robotic and Viking scenarios outright, but saw it as part of a grander strategy that would be more difficult to halt due to political whims once in progress:

[52] On a similar, but more humanistic note, **one participant saw the act of settlement as pushing the boundaries of what it means to be human, *"the human experience of living on Mars, a human waking, living, solving problems, writing poetry, making art, yearning for Earth make colonization, the risks and costs seem trivial."*** The intended point seems to be that we, as a species, have something to gain by simply inhabiting Mars; there is new knowledge to be gained through the simple experiences of life in a different context.

"Really a combination. Missions should be sent incrementally like Viking, but a permanent or sustained exploration strategy is important to make sure that it's difficult for politics to end the program like Apollo."

Debates about Values and the Goals for Exploration

As can be seen above, **people can have conflicting values about what should be pursued in space, which changes the way the deliberation proceeds.** Table observations are another way that we can map values and bring an understanding to how they shape discussions. They can highlight what was discussed prior to participants providing their filtered responses to voting questions, and provide additional insight into how people formed rationales. The Journey to Mars session ended up representing a chance for participants to break out of the relatively technical and governance-oriented design of the "Informing NASA's Asteroid Initiative" forum. In this session participants raised familiar values questions around space exploration (e.g., enthusiasm for becoming an Earth-independent species vs. concern that priority should be given to problems on Earth) that were not addressed elsewhere in the design of the forum.

The unique issues bound up with the Journey to Mars session were aptly expressed by one table facilitator, who opened the session by saying that this session might be *"more interesting maybe"* than those that had preceded it. Clearly, participants in general found all the discussions interesting and important, but most of the previous sessions addressed technical issues such as ground-based vs. space-based detection, or different methods for redirecting an asteroid. While some of the questions posed to participants engaged political values, such as how much foreign countries can be trusted as collaborators in space exploration, these discourses were framed within a management perspective that explored *how* a given program might be pursued, rather than whether or not it *should be* pursued.

The facilitator who noted that the Journey to Mars session might be more interesting seemed to be indicating that the topic could touch on more fundamental questions about humanity's relationship to the Earth and the nature of progress. Whether or not that was his intent, within a few minutes **one participant broke the pattern of a mostly technical-managerial discussion of Mars exploration options by stating, "I don't recall hearing a purpose for this," to which another participant immediately responded, "To be Earth-independent." From that point forward a lively conversation ensued in which technical and managerial arguments were interspersed with divergent perspectives on the basic purposes of human exploration of Mars.** Similar issues arose at most of the other tables observed, as reflected in the review of qualitative results for the Mars session.

In essence, unlike earlier sessions (planetary defense and ARM), the Journey to Mars session provided an environment where people felt more comfortable expanding on their values. Even though the session was initially constrained by technical considerations and whether the Proving Ground strategy was a viable course of action for NASA, it led to a more open-ended discussion of why we should explore outer space in the first place. As a consequence of these results, ECAST feels that a design question for further inquiries into citizen views on human exploration of Mars is whether a conversation that directly engaged the purposes as well as the means of such exploration would be more robust. That is to say, a deliberation where a focused debate on the "whys" of exploring Mars prior to a discussion of how to plan missions to Mars could be a valuable focus of research.

6.4.2 Assessing the Proving Ground and Capability-driven Framework Results

We believe that the vote on behalf of the Proving Ground strategy provides some support that an informed public may be accepting of the capability-driven framework. In this section and the subsequent text box, we analyze the written responses given to the question of the Proving Ground's acceptability. If this assertion can be supported, an important question to consider is whether participants actually saw the Proving Ground question through the CDF? The analysis below was designed to answer this question.[53] In short, we searched all participant rationales (N=184), for one of the three critiera implied by the CDF definition:

1) Incrementalism – Instead of traditional destination-oriented missions, this approach does not need final, fixed goals in place before initial missions are carried out. Technologies can be developed, tested, refined, and perfected in lower-risk environments in incremental steps.
2) Multi-purpose missions – The outcomes of the missions reflect the ability to be flexible and adaptive in relation to future mission choices. Technologies that are developed can be used for a variety of purposes rather than specifically defined destinations.
3) Budget constraints – The incrementalism of CDF fits well with NASA's evolving budget climate. Missions can be planned based on available budgets.

We used these three criteria to determine if participants' written rationales showed an understanding of the Proving Ground question in terms of CDF. If a statement included at least one of the three components above, we considered it a rationale based on CDF reasoning (Yes). If the statement didn't have any of the components, we considered it not to be based on CDF reasoning (No). We created a third category for ambiguous statements, ones that could be interpreted in light of CDF, but not definitively (Maybe). Table 6.4 shows that 50.6% of participants use CDF language in their rationales. The rest of the participants were either in the "No" or "Maybe" categories. Box 6.3 provides a sample of the different ways that people constructed rationales on the Proving Ground question.

[53] We should note that when doing the analysis, it became obvious that is difficult to determine if people didn't understand the Proving Ground question through CDF. In other words, we can demonstrate where people clearly understood the proving ground question in terms of CDF (50.6% of participants used CDF language in their rationales), but due to the nature of data collection, definitively determining what percent of the participants understood the question in this way is impossible (the other 49.4% of the participants are in this category). Just because someone didn't use the language doesn't mean they didn't understand the idea; for example, several people objected to or weren't sure about the Proving Ground strategy because of ethical considerations (e.g., we have bigger problems on Earth that haven't been addressed).

Table 6.4 –Proving Ground strategy written rationale analysis. ***The numbers of participants that did (Yes) and didn't (No) use the three major components (incrementalism, multipurpose missions, and budget constraints) of CDF in their rationales for either supporting or not supporting the Proving Ground strategy during the Mars session. A third category (Maybe) was used for ambiguous rationales in relation to the proving ground strategy—rationales that are possible to interpret in light of CDF, but not definitive. Each rationale in these categories is broken down by the Proving Ground vote it supported (far left column). The data below represent Arizona and Massachusetts combined (N=184) Note: The patterns were similar between Arizona and Massachusetts.***

Proving Ground Vote	***Yes (At least 1 of the 3 major components of the CDF definition present in the rationale)***	***No (None of the 3 major components of CDF definition present in the rationale)***	***Maybe (Possible to interpret in light of CDF, but not definitive)***	***No comment given***
Yes	70	27	26	1
Not Sure	18	14	10	9
Doesn't fit at all	4	2	1	2
Total	92 (50.0%)	43 (23.4%)	37 (20.1%)	12 (6.5%)

Box 6.3 – Example rationales of participants that did and didn't frame their rationales in terms of the CDF. Each statement is followed in parentheses by its category (Yes, No, Maybe) and what CDF criteria it satisfied. The full set of written rationales is included in Appendix E.

Statements that Support CDF (Yes)

I think all of the proving ground approach allows us to maximize learning opportunities and minimize costs - essentially more bang for our buck with space of flexibility. ***(Yes: Incrementalism, Multipurpose Missions, Budget Constraints)***

I think small incremental steps lead to the best science and are the most practical. ***(Yes: Incrementalism)***

It's evolutionary, addressing problems known now and could adapt to address others in future. ***(Yes: Incrementalism, Multi-purpose Missions)***

It allows us to continue towards a larger goal in smaller steps, which are easier politically and financially viable. ***(Yes: Incrementalism, Budget Constraints)***

I fear that any step in the process people could lose interest/pull tax funding and therefore going to Mars immediately would be better. ***(Yes: Incrementalism, Budget Constraints)***

Small and steady wins the race. You have the option to learn and gain expertise as you go along, while (illegible) risk in loss of life ***(Yes: Incrementalism)***

Going to mars necessitates overcoming many obstacles …. These solutions can be applied to all kinds of space exploration. Get the asteroids threatening Earth first. ***(Yes: Incrementalism, Multipurpose Missions)***

I'm afraid that piecemeal approach lacks accountability. It's easy to just give up. ***(Yes: Incrementalism)***

It makes sense to me to work with what you have. Obviously humans are interested in going to Mars, but even smaller victories are engaging. People have been very excited about the recent ESA mission and the comet for instance. ***(Yes: Incrementalism, Multipurpose Missions)***

Statements that Don't Demonstrate CDF (No)

Not sure how pressing it is when so many current issues and problems still exist on our planet. ***(No)***

We need a clear goal to capture imagination. ***(No)***

Not sure how pressing it is when so many current issues and problems still exist on our planet. ***(No)***

I have mixed feeling on "intruding" on another planet. ***(No)***

Statements that are Ambiguous (Maybe)

We should move forward with everything that could enhance space exploration. These could lead to some big discoveries and advancements such as finding better ways to defend and protect Earth. ***(Maybe: Multi-purpose Missions)***

I think that given the unfavorable political climate for space exploration, the Proving Ground Strategy is a very good idea. Will give a chance to develop technology in a replicable way. ***(Maybe: Multi-purpose Missions)***

Table observations also corroborate the claim that the public accepts aspects of CDF and the Proving Ground strategy. According to these observations, many participants embraced what in effect was a Proving Ground strategy before it came up for explicit discussion in this session. For example, multiple groups at both the Arizona and Massachusetts deliberations introduced the idea of using robotic missions, possibly with humans based on a Martian moon (orbital/robotic option), to prepare for long-term settlement (Pioneer). These discussions suggest that many participants implicitly accept the logic of a Proving Ground strategy as it relates to CDF. One table observer noted that, for his table, the discussion generally adhered to "*the principle that technologies should be proven and developed in a responsible and deliberate manner*." Participants at other tables in both Arizona and Massachusetts invoked a similar logic, but with different specifics. For example, one participant in Massachusetts argued that *"the robots could start to prepare the colony"* (Pioneer), minimizing the risk to humans, while several participants at another Massachusetts table argued for pursuing robotic and moon missions in preparation for a Pioneer strategy solely based on the economic consideration that the robotic approach would be less expensive. Overall these observations may indicate that participants supported the generic idea of a Proving Ground strategy, even though they may not have fully embraced NASA's formal version of it.

In sum, we believe the majority of participants understood the Proving Ground question in terms of the CDF, which has shaped much of NASA's recent mission planning. This result suggests that if the public were made more aware of the CDF and the constraints NASA operates under, then they may be more receptive to an incremental mission-planning strategy. If an argument for the capability-driven framework was made in contrast to more traditional destination-oriented mission frameworks (e.g., the Apollo missions), the public might be receptive to it. However, the data are not definitive and indicate that more careful articulations of the CDF will be required for the public to fully understand and embrace the concept. For instance, many participants had a good sense of the CDF, as indicated by this participant's rationale: *"I think all of the proving ground approach allows us to maximize learning opportunities and minimize costs - essentially more bang for our buck with space of flexibility*." But other statements were more ambiguous, sometimes conflating incremental Proving Ground missions as budget dictates with notions of long-term plans that necessarily lead to humans landing on Mars.

In essence, some participants may be intentionally or unintentionally hybridizing the traditional mission model with the CDF. This could be a product of introducing CDF in the context of a session designed to assess people's opinions about preferences of different Mars exploration scenarios. As such, **the results show some ambiguity, suggesting that complicated concepts such as the Proving Ground and CDF deserve more focused attention during a deliberation so that people have time to assimilate what it actually means in the context of space exploration. Our recommendation for future deliberations is that a separate session be devoted to the CDF concept prior to having people address its merit relative to any sort of mission (e.g., Mars, ARM, etc.).**

Part III – Reflections and Refinements

7.0 Reflections and Refinements

This project yielded many significant insights, which we highlighted in the results sections above. We will not summarize those results here, though an overview can be found in the Executive Summary above as well as in the short version of this report at the project website: http://cspo.org/research/a-participatory-technology-assessment-of-nasas-asteroid-initiative/). Instead, we will offer a few final reflections about two of the project design components:

- First, what aspects of the **citizen forum** could be improved, and what issues could be productively explored further?
- Second, how can this **project model** be used in the future, and what variations of the model might be adopted to support decisions that are broader or different in scope?

7.1 Refining The Forum Design

Several aspects of the project were experimental, and could be refined and improved on in future work. One macro-level issue arose which added time pressure to the partnership: the timeline for the project was changed during the project because NASA liaisons saw an opportunity to use the results of the Asteroid Redirect Mission session as background information for a near-term decision about which ARM option the agency should embrace. This shortened an already tight timeline from six to five months, reducing the time available to design the project, develop background materials, arrange logistics, and complete participant recruitment.

Although the participant comments in the post survey were very positive about the quality of all aspects of the event (see section 2.6.4), a design period compressed to meet decision deadlines pushed the limits of what the staff could prepare and the participants could digest. Some of the confusion expressed by participants in the course of their deliberations likely would have been ameliorated had the extra month been available to refine the design and test information materials through focus groups. Even without refinements, more lead time for participants to read the advance information material would have increased their comprehension of it. There is a trade-off here, however: the tightened time line *did* produce useful input for an important decision in a timely fashion, an outcome that often eludes cooperative arrangements such as the one undertaken in this project.

Based on our experience, there are several additional ways to improve the participatory technology assessment approach using a dialog format. Table 7.1 discusses some of the key factors that could be changed or reemphasized in future research.

Table 7.1 Influential Factors in Forum Design and Recruitment

Influential Design Factors	Description
Participant Demographics and Knowledge	Each participant has different levels of preparation and different social and cultural associations with the topic of deliberation. Participants also have varying levels of energy and enthusiasm related to the particular time that a decision is put forward (e.g. table observers noted that energy levels were lower after lunch when the ARM session occurred). Participant demographics show the composition of the two site groups, but not by individual voting response**. Careful analysis of survey questions could better capture what perspectives participants bring to the forum**. **Furthermore, voting responses could ask for basic demographic information (e.g., gender) of particular interest so we could more closely tie individual responses to demographic patterns.**
External Information and Media Coverage	Media coverage that related to one or more of the issues associated with the deliberation occurred in the weeks before the in-person events (e.g., for ARM, the European Space Agency's mission to a comet occurred in between the two forums). **Adjustments to the pre- and post-forum test instruments could test for the influence of this type of external information**.
Information Materials Created for the Event	Participants were given background materials to read before the event and were shown a video at the beginning of each session where their task was to deliberate on different key questions. It is possible that the background material in different sections may have influenced participants' preferences. **Additional time to test the background materials and session design in advance, potentially by testing it with control groups, would help to mitigate this factor.**
Table Facilitation	Table facilitators received training about the information materials, process, and intended outcomes of each session. Facilitators came from a range of backgrounds and had different levels of exposure to training for professional facilitation. **Ensuring best practices and shared knowledge among facilitators could help increase consistency in the forum process.**
Balance and Influence of Group Discussion Versus Iindividual Voting and Reasoning	Participants engaged in facilitated discussion for approximately 1 or 1.5 hours on a given topic, so they were able to learn what their fellow participants thought and to explore reasoning behind their statements before making a personal vote. This is one of the strengths of this dialog model for a pTA deliberation, and could be further used to shape future research.

7.2 Improving Decision Support

We believe much of value was discovered through these forums**—a diverse and rich set of data relevant to specific questions about NASA's Asteroid Initiative that could provide useful input to agency decision makers.** Below are four potential ways to broaden the scope of future projects to address issues facing NASA and perhaps other federal agency administrators.

First, the deliberation on asteroid detection and mitigation of asteroid threats raised issues about how the public conceives of opportunity costs in space. Participants discussed costs in several key places, but given that the session didn't specifically focus on cost, we have difficulty determining exactly what participants felt about the opportunity costs of the three asteroid detection methods. A more general discussion of opportunity costs between funding a space-based effort versus other alternative projects, both space related and non-space related, is possible. Past exercises, such as Budget Hero,[54] have involved giving citizens an overview of the entire federal budget, inviting them to try to make systemic changes to resolve issues. **A public deliberation could provide relevant background and explore more precisely how much priority costs for specific federal projects would be publicly desired given competing goals.** For instance in the present case, a forum could be devoted to discussing specifically the opportunity costs of implementing different mitigation strategies or asteroid detection methods.

Second, understanding how the public perceives probabilities emerged as an interesting topic of research in the asteroid mitigation section. Participants considered ten different scenarios, and their perception of different probabilities in those scenarios altered their preferred mitigation strategies and institutional leaders. Surprisingly, a majority of participants selected the use of nuclear blast deflection as a mitigation strategy, especially when facing increased risk of large-scale impacts. However, upon further analysis, it became evident that most participants did not make the choice lightly. Many showed great reluctance and resignation that this was their only choice given the circumstances. **Additional deliberations with more scenarios could be used by decision makers to better understand how the public would perceive probabilities of threats, accept institutional actors, and choose conditions for various mitigation options.**

Third, **the ARM results indicate that using pTA to proactively support a technical decision could be valuable for a variety of topics, both in aerospace as well as other areas of the federal government.** The ARM decision between Options A and B was a fairly technical and challenging topic, yet participants generally were able to navigate through the technical complexities and have a nuanced discussion of the decision variables. In addition, participants had rich discussions about potential goals for the mission, about risk, and about schedule priorities, which are useful data points to consider when trying to understand how people view different initiatives. **Future research could examine the value that NASA derived from the deliberation results, ways the deliberation could be more precisely structured to provide results that better help NASA's decision making.**

Fourth, as noted in Section 6, **more explicit deliberation about the value or purpose of the missions themselves could be beneficial, such as a deliberation focused on why humans should go to Mars in the first place.** Similar questions could also be asked about the concern in or interest about asteroids, or retrieving and visiting one. The congressional mandate to detect 90% of all asteroids by 2020 was the starting point for the planetary defense sessions on detection and mitigation. Similarly, the ARM session emanated from President Obama's goal for astronauts to visit an asteroid by 2025. The design of the Journey to Mars session focused on how to manage a program for human exploration, such as with the capability-driven framework. The deliberations did not explicitly focus on the goals to be served by asteroid detection, mitigation, and recovery and Mars exploration and the philosophical commitments that underlie them. Nonetheless, participants had plenty to say on matters of philosophical import, and made, at times, conflicting opinions about the relative values of different scenarios for the various missions. Discussions would likely have been even more robust had values been engaged more explicitly by design, for example as an exercise in mapping public values (see Footnote 2 in Section 2.2). This would

[54] http://www.wilsoncenter.org/budget-hero

require introducing not only the technical complexities surrounding the issues at hand, as we did in this forum, but also their social, ethical, and legal dimensions, and engaging with a broader group of experts and stakeholders.

Interestingly, despite the philosophical differences among participants in the Mars session, there was considerable convergence on the desirability of continued space exploration within a capability-driven, or Proving Ground, framework. **This may suggest that the "crash program" models of the Manhattan Project to produce an atomic bomb and the race to be the first to the moon are artifacts of a bygone era. For space exploration in the 21st century, a measured and considered program that takes advantage of opportunities and resources over time was clearly preferred by a significant majority of participants in this forum, including some (based on table observations) who have reservations about human space exploration.**

Appendices

Appendix A – Participant Demographics

Category	US population	AZ + MA Participants	AZ Population	AZ Participants	AZ Applicants	MA population	MA Participants	MA Applicants
Total population (1)	309,138,711	13,319,448	6,626,624	96	286	6,692,824	87	180
Sex (2)								
Male	49.2%	50.8%	49.7%	56.3%	57.7%	48.4%	44.8%	54.7%
Female	50.8%	49.2%	50.3%	43.8%	42.3%	51.6%	55.2%	45.3%
Age (3)								
Median	37.2		36			39.1		
18-24	13.1%	22.4%	13.3%	30.2%	45.5%	13.1%	13.8%	35.4%
25-44	35.0%	41.5%	35.3%	32.3%	32.2%	33.9%	51.7%	40.1%
45-64	34.6%	28.4%	32.8%	26.0%	17.5%	35.2%	31.0%	20.4%
65 plus	17.3%	7.7%	18.6%	11.5%	4.9%	17.7%	3.4%	4.1%
Education (4)*								
No HS degree	14.4%	2.2%	14.6%	3.1%	1.0%	10.9%	1.1%	0.9%
HS degree	28.5%	11.5%	24.4%	18.8%	21.3%	25.9%	3.4%	15.2%
Some college, no degree	28.9%	27.9%	34.4%	36.5%	37.4%	24.3%	18.4%	29.8%
Bachelor's degree	17.7%	34.4%	16.9%	28.1%	26.9%	22.2%	41.4%	32.4%
Graduate degree	10.4%	24.0%	9.7%	13.5%	13.3%	16.8%	35.6%	21.7%
Race/Ethnicity (5)								
White	63.7%	59.0%	57.7%	46.9%	60.1%	76.3%	72.4%	63.9%
Black	12.2%	5.5%	3.8%	5.2%	3.8%	6.2%	5.7%	5.6%
Asian	4.7%	6.6%	2.7%	8.3%	9.1%	5.4%	4.6%	8.8%
Mixed/other	2.4%	6.0%	1.7%	4.2%	8.4%	1.7%	8.0%	6.9%
Hispanic	16.3%	23.0%	29.7%	35.4%	18.5%	9.6%	9.2%	14.8%

Participant Demographics (cont.)

Category	US population	AZ + MA Participants	AZ Population	AZ Participants	AZ Applicants	MA population	MA Participants	MA Applicants
Household Income (6)								
Prefer Not to Disclose	n.d.	18.6%	n.d.	20.8%	21.7%	n.d.	16.1%	17.8%
Less than $25,000	24.9%	21.9%	23.6%	29.2%	25.2%	20.0%	13.8%	21.5%
$25,000 to $49999	25.0%	21.9%	26.2%	16.7%	19.2%	18.7%	27.6%	21.2%
$50,000 to $99,999	30.1%	25.1%	30.9%	20.8%	20.6%	29.3%	29.9%	25.1%
$100,000 or more	20.0%	12.6%	19.4%	12.5%	13.3%	31.8%	12.6%	14.4%
Occupations								
Employed		56.8%		49.0%	42.3%		65.5%	52.6%
Unemployed		8.2%		9.4%	8.0%		6.9%	7.9%
Retired		6.6%		10.4%	5.9%		2.3%	4.5%
Student		18.0%		25.0%	37.8%		10.3%	27.3%
Other		10.4%		6.3%	5.9%		14.9%	7.7%
NASA Related								
Attend NASA Social?		7.1%		6.3%	7.0%		8.0%	10.1%
Member space advocacy group?		4.9%		7.3%	10.1%		2.3%	8.4%
Aerospace professional?		1.6%		1.0%	5.9%		2.3%	6.0%
Political Orientation (7)								
Very conservative	10%	0.0%		0.0%	0.3%		0.0%	0.2%
Conservative	30%	11.5%		14.6%	12.2%		8.0%	11.8%
Moderate	35%	38.8%		40.6%	39.5%		36.8%	38.2%
Liberal	15%	34.4%		25.0%	31.1%		44.8%	35.0%
Very liberal	6%	3.3%		3.1%	4.5%		3.4%	4.9%
No opinion	4%	12.0%		16.7%	12.2%		6.9%	9.9%

Sources:

1. U.S. Census Bureau, State & County QuickFacts (2013 estimate)
2. U.S. Census Bureau, American FactFinder, Table Age and Sex (2008-2012 American Community Survey 5-Year Estimates)
3. U.S. Census Bureau, American FactFinder, Table Age and Sex (2008-2012 American Community Survey 5-Year Estimates)
4. U.S. Census Bureau, American FactFinder, Table EDUCATIONAL ATTAINMENT (2008-2012 American Community 5-Year Estimates) *25 years or older
5. U.S. Census Bureau, American FactFinder, Table ACS DEMOGRAPHIC AND HOUSING ESTIMATES (2008-2012 American Community Survey 5-Year Estimates)
6. U.S. Census Bureau, American FactFinder, Table SELECTED ECONOMIC CHARACTERISTICS (2008-2012 American Community Survey 5-Year Estimates)
7. Lydia Saad, 'Conservatives remain the largest ideological group in the U.S.', Gallup Politics, January 12, 2012

Appendix B – Asteroid Detection Qualitative Results

(Data not discussed in above section) To best understand these results, first see a description of the questions and deliberation format discussed in the appropriate section above.

Table B-1 – *Common themes that emerged from participants forming group plans about which detection method they supported and the institutional leaders each group believed would be best suited to govern the implementation of their preferred detection method.*

Theme code & scope note	Group Plan	Table #	Location
Global issue/Responsibility - Group plan acknowledges that the issue of detection is a global concern and responsibility.	1. Combining Detection 2 and 3 2. Necessary to cover land and space, long-term investment (investing in financial and political stable countries) 3. First designate NASA as secretary of planetary defense establish credibility, then guardianship of UNOOSA	**1**	**MA**
	Space-based observations w/ satellites supplemented w/ current detection & extended ground-based network. International consortium w/ NASA supported by private industry & scientific/academic community using CERN as a model.	**3**	**MA**
	We chose D3 because it will provide the best detection capabilities. We believe that a collaborative guardian will be most effective for sharing of the information and responsibility, led by the UN. This will allow multiple groups and countries to have equal access to the data and budget costs. Efforts should also be made to extend ground-based detection as secondary priority.	**4**	**MA**
	We would enact option #3 (if money was not an isue, we would also include #2). It seems like it actually makes a significant difference. We would want the plan to be enacted by a combinaiton of the UN, a US-ed international partnership + the academi community.	**15**	**MA**
	Detection: Options 2 & 3. 80/20% funding. Start with extended ground then invest long term in space-based. Guardians: combo of 3 & 6. NASA led, but with gov and nonprofit funding. Also international information sharing. And ideally international funding.	**1**	**AZ**
	Detection . Implementation by Intl Consortium & Intl Sci Community/Academic. Group believes best detection outcomes will result. ISO9000 ICCAN.	**2**	**AZ**
	Space-based observation from satellites led by the US leading an international partnership to fund private industry and work with international scientific/academic community. We chose these guardians because it's a global issue that can benefit from private industry resources and the scientific/academic community.	**12**	**AZ**

	Private industries working together with scientist will have the motivation and resources. The UN could oversee the efforts of these groups, while having the trust and authority of the world community and ability to redirect a portion of private profits.	**13**	**AZ**
	Collaborative global decision. Allocation of funds from contributors around the world. Creates univ. collaboration domestically & int'l > prevention & devel. Greater possbility of being research based. Generates global conversation about the projects with the int'l public.	**14**	**AZ**
Expertise - Group plan highlights the value of expertise, sometimes explicitly across sectors.	#3. The risk of asteroid impact is too great to ignore. This option addresses all issues and is the most effective. (4) UNOOSA + international scientific/academic community (6). These are science-based, led by experts in their fields. It's a shared expense with trust and collaboration.	**9**	**MA**
	Options for detection: primarily #3 while maintaining #1. Guardians: #3 with advisory board of #6.	**10**	**MA**
	Detection - combination of land-based + space-based capabilities need to enlist international support for this as a priority, suggest crowd-source funding to contrbute to these efforts. Guardian #3 US-led international partership, build on NASA expertise & capablity; expand available resources and ownership globally.	**11**	**MA**
	We recommend advancing D#3 as the most effective solution to be employed by G#3 (US lead) and G#6 (academic) as they are the most experienced, capable, and trustworthy to employ alternative with the greatest opportunity for success.	**5**	**AZ**
	Capable of giving most accurate results. Better chance of getting funding. Minimize special interest groups. Shared information. Accountability. As a group we chose Detection #3: Guardian #3 Guardian #4. Questions remaining: 1. Larger climate effects. 2. What is the cost impact to AZ? 3. Where would the funds draw from?	**6**	**AZ**
	Space-based detection is the most feasible option. The US should lead the international partnership utilizing the established infrastructure. We believe using the expertise of NASA helps ensure the success of this endeavor where the international partnership helps ensure fairness, inclusion & costs. We also think that international academic communities & private industries should provide the expertise & funding for the work.	**7**	**AZ**

	Trust, focus, collaboration, funding regulation. Take asteroid expertts from NASA? Combo of detection #2 and #3. Neutral body involved even if big US role. Advisory board with people from around world. Non-profit, NASA & focused, disareement re:NASA. Experts from around the world/technocratic.	**8**	**AZ**
	Guardian #3. NASA is trusted. Internationally funded (3) 100 mil not a lot of $ - considering benefits. The US is the leader of asteroid detection. International partners look to US (NASA) to lead + be accurate. It's insurance for future catastrophes. The threat is REAL! It will detect virtually ALL ASTEROIDS! Therefore, we choose detection method 3.	**9**	**AZ**
Economic - Group plans emphasize economic concerns or factors.	1. Combining Detection 2 and 3 2. Necessary to cover land and space, long-term investment (investing in financial and political stable countires) 3. First designate NASA as secretary of planetary defense establish credibility, then guardianship of UNOOSA	**11**	**MA**
	Detection #3 It is an investment rather than a cost. The #1 benefit is very compelling - providing full coverage. Evaluate use of non-NASA existing space assets. Evaluate cost vs. benefit of all options. We have three guardian choices #3, #5, #1 not in that order.	**3**	**MA**
	With many caveats, we agreed (generally) that the program should include Option 3, and option 1 should continue to exist and function. The group felt option 3 was more proactive and comprehensive, but there were deep concerns/reservations about funding and the true degree of the threat. The most compelling guardian was #6 citing intellectual capacity, separation from political and financial influence (IF funding already a given), and would likely be seen as the most fair internationally. NASA should also play critical role.	**2**	**AZ**
	Capable of giving most accurate results. Better chance of getting funding. Minimize special interest groups. Shared information. Accountability. As a group we chose Detection #3: Guardian #3 Guardian #4. Questions remaining: 1. Larger climate effects. 2. What is the cost impact to AZ? 3. Where would the funds draw from?	**6**	**AZ**
	Guardian #3. NASA is trusted. ***Internationally funded (3) 100 mil not a lot of $ - considering benefits.*** The US is the leader of asteroid detection. International partners look to US (NASA) to lead + be accurate. It's insurance for future catastrophes. The threat is REAL! It will detect virtually ALL ASTEROIDS! Therefore, we choose detection method 3.	**7**	**AZ**

New Institution - Group plans recommend the formation of a new institution or agency office.	Detection 02 Extended ground-based network. Detection 03 - spae based observation from satellites. Detection 04 - Citizen scientists. Guardian 03 - US leading international partnership. Guardian 06 - Intl scientific/academic community. Guardian 05 - Private industry. Guardian 02 - New US office of planetary defense.	**6**	**AZ**
	Creating an office of Planetary Defense guarded by the international partnership (NASA, other space and private industries) to realize space-based observation from satellites.	**7**	**MA**
Trust/Equity/accountability - Group plans include mention of concerns about recommendations addressing equity, trust, accountability related to the choice of guardians.	We recommend advancing D#3 as the most effective solution to be employed by G#3 (US lead) and G#6 (academic) as they are the most experienced, capable, and trustworthy to employ alternative with the greatest opportunity for success.	**5**	**AZ**
	Space-based detection is the most feasible option. The US should lead the international partnership utilizing the established infrastructure. We believe using the expertise of NASA helps ensure the success of this endeavor where the international partnership helps ensure fairness, inclusion & costs. We also think that international academic communities & private industries should provide the expertise & funding for the work.	**7**	**AZ**
	Space-based detection w/ ground-based backup. Led by US-led int consortium. Rationale - scientific com more trusty w/ NASA storn gcurrent leader to increase likelihood of success & collaboration. 2 funding pools - int'l & private	**10**	**MA**
US Leadership - Group plans explicitly mention the need for US leadership	Our group prefers detection 2 and 3 as a combination. We liked detection 3 the best, but we want detection 2 as another option. The U.S. leading an international partnership should be responsible while bringing international partners with the U.S. leading.	**11**	**AZ**
	Detection Option 3 has successful, definitive outcome - can follow through on assignments from US congress (90% detection). Needs to be some government oversight (NASA). w/ private coprs investing $, mitigating expense of option 3. academic/[???] enhances other research opportunities without alterior motives.	**5**	**MA**
	NASA is existing leader in asteroid detection. The US should lead in global collaboration. Scientific ethics keeps us honest while politics and business always has an agenda. Therefore we propose detection #3 + #2 collaborate with guardians #3 & 2 - One detecting & other overseeing.	**4**	**AZ**

Research - Group plans acknowlege the value of academic and industry research as a product of and a source informing detection activities.	Space-based detection w/ ground-based backup. Led by US-led int consortium. Rationale - scientific com more trusty w/ NASA storn gcurrent leader to increase likelihood of success & collaboration. 2 funding pools - int'l & private	**10**	**MA**
	Collaborative global decision. Allocation of funds from contributors around the world. Creates univ. collaboration domestically & int'l > prevention & devel. Greater possbility of being research based. Generates global conversation about the projects with the int'l public.	**14**	**AZ**
	We would enact option #3 (if money was not an isue, we would also include #2). It seems like it actually makes a significant difference. We would want the plan to be enacted by a combinaiton of the UN, a US-ed international partnership + the academi community.	**15**	**MA**
Private Industry Leadership - Group plans explicitly mention the need for US leadership/involvement.	Space-based observation from satellites led by the US leading an international partnership to fund private industry and work with international scientific/academic community. We chose these guardians because it's a global issue that can benefit from private industry resources and the scientific/academic community.	**12**	**AZ**
	Private industries working together with scientist will have the motivation and resources. The UN could oversee the efforts of these groups, while having the trust and authority of the world community and ability to redirect a portion of private profits.	**13**	**AZ**
	Combine 2 + 3 - Question about implementation stage*. >Why? 1 is not an option - not opimal, other economic/educational benefits, science gain *there are many options! Guardians: US led international partnership w/ NASA in charge; include private industry. Dissenting - leapfrog to 3.	**8**	**AZ**

Table B-2 - All of the group plans generated during the Detection session at both sites (Arizona – AZ and Massachusetts – MA) that considered the cost of implementing the three different detection strategies: 1) Ground based status quo, 2) Extended ground-based observation, and 3) Space-based detection. Ten out of fifteen group plans in Arizona considered costs and eight out of twelve group plans in Massachusetts considered costs. Note: All phrases related to costs below are highlighted with italicized bold type.

Site/Group	*Group Plan*
AZ – 1	Space-based observation from satellites led by the US leading an ***international partnership to fund*** private industry and work with international scientific/academic community. We chose these guardians because it's a global issue that can benefit from ***private industry resources*** and the scientific/academic community.
AZ – 2	With many caveats, we agreed (generally) that the program should include Option 3, and option 1 should continue to exist and function. The group felt option 3 was more proactive and comprehensive, but ***there were deep concerns/reservations about funding and the true degree of the threat***. The most compelling guardian was #6 citing intellectual capacity, ***separation from political and financial influence*** (***IF funding already a given***), and would likely be seen as the most fair internationally. NASA should also play critical role.
AZ – 3	Detection: ***Options 2 & 3. 80/20% funding***. Start with extended ground ***then invest long term in space-based***. Guardians: combo of 3 & 6. NASA led, but ***with gov and nonprofit funding***. Also international information sharing. ***And ideally international funding***.
AZ – 4	Trust, focus, collaboration, ***funding regulation***. Take asteroid experts from NASA? Combo of detection #2 and #3. Neutral body involved even if big US role. Advisory board with people from around world. Non-profit, NASA & focused, disagreement re: NASA. Experts from around the world/technocratic.
AZ – 7	Guardian #3. NASA is trusted. ***Internationally funded (3) 100 mil not a lot of $ - considering benefits.*** The US is the leader of asteroid detection. International partners look to US (NASA) to lead + be accurate. It's insurance for future catastrophes. The threat is REAL! It will detect virtually ALL ASTEROIDS! Therefore, we choose detection method 3.
AZ – 8	Private industries working together with scientist will have the motivation and ***resources***. The UN could oversee the efforts of these groups, while having the trust and authority of the world community and ***ability to redirect a portion of private profits***.
AZ – 9	Combine 2 + 3 - Question about implementation stage*. >Why? 1 is not an option - not optimal, ***other economic/educational benefits***, science gain *there are many options! Guardians: US led international partnership w/ NASA in charge; include private industry. Dissenting - leapfrog to 3.
AZ – 11	Capable of giving most accurate results [space-based observation]. ***Better chance of getting***

	funding. Minimize special interest groups. Shared information. Accountability. As a group we chose Detection #3: Guardian #3 Guardian #4. Questions remaining: 1. Larger climate effects. 2. ***What is the cost impact to AZ?*** 3. ***Where would the funds draw from?***
AZ – 13	Space-based detection is the most feasible option. The US should lead the international partnership utilizing the established infrastructure. We believe using the expertise of NASA helps ensure the success of this endeavor where ***the international partnership helps ensure fairness, inclusion & costs.*** We also think that international academic communities & private industries should ***provide the expertise & funding for the work***.
AZ – 15	Collaborative global decision. ***Allocation of funds from contributors around the world***. Creates univ. collaboration domestically & int'l > prevention & devel. Greater possibility of being research based. Generates global conversation about the projects with the int'l public.
MA – 2	Detection Option 3 has successful, definitive outcome - can follow through on assignments from US congress (90% detection). Needs to be some government oversight (NASA). ***w/ private corps. investing $, mitigating expense of option 3***. academic/[???] enhances other research opportunities without ulterior motives.
MA – 3	We would enact option #3 (***if money was not an issue, we would also include #2***). It seems like it actually makes a significant difference. We would want the plan to be enacted by a combination of the UN, a US-led international partnership + the academic community.
MA – 4	Space-based detection w/ ground-based backup. Led by US-led int. consortium. Rationale - scientific com more trusty w/ NASA strong current leader to increase likelihood of success & collaboration. 2 ***funding pools - int'l & private.***
MA – 5	Detection - combination of land-based + space-based capabilities need to enlist international support for this as a priority, ***suggest crowd-source funding to contribute to these efforts***. Guardian #3 US-led international partnership, build on NASA expertise & capability; expand available resources and ownership globally.
MA -7	We chose D3 because it will provide the best detection capabilities. We believe that a collaborative guardian will be most effective for sharing of the information and responsibility, led by the UN. This will allow multiple groups and countries to have ***equal access to the data and budget costs.*** Efforts should also be made to extend ground-based detection as secondary priority.
MA – 8	#3. The risk of asteroid impact is too great to ignore. This option addresses all issues and is the most effective. (4) UNOOSA + international scientific/academic community (6). These are science-based, led by experts in their fields. ***It's a shared expense with trust and collaboration.***
MA -10	Detection #3. ***It is an investment rather than a cost***. The #1 benefit is very compelling - providing full coverage. Evaluate use of non-NASA existing space assets. ***Evaluate cost vs. benefit of all options.*** We have three guardian choices #3, #5, #1 not in that order.

MA – 11	1. Combining Detection 2 and 3 2. Necessary to cover land and space, long-term investment (***investing in financial and political stable countries***) 3. First designate NASA as secretary of planetary defense establish credibility, then guardianship of UNOOSA.

Appendix C – Asteroid Mitigation Quantitative Results

To best understand these results, first see a description of the questions and deliberation format discussed in the appropriate section above.

Table C-1: The percentage of times participants wrote down "Gravity Tractor" as an "Other" option in Massachusetts, Arizona, and both combined. The n-number for each result below is different because different numbers of participants selected "other" at different frequencies for each scenario.

Scenario	*MA*	*AZ*	*Combined*
Scenario 2A	NA	63.0% (n=27)	NA
Scenario 2A-1	92.6% (n=27)	58.3% (n=24)	76.5% (n=51)
Scenario 2A-2	95.5% (n=22)	52.4% (n=21)	74.4% (n=43)
Scenario 2B	NA	44.4% (n=18)	NA
Scenario 2B-1	56.3% (n=16)	42.1% (n=19)	48.6% (n=35)
Scenario 2B-2	72.0% (n=25)	54.1% (n=37)	61.3% (n=62)

Note: Due to an omission error, participants in Arizona weren't presented with the chance to vote for Gravity Tractor on any voting sheet, yet they still chose Gravity Tractor at a fairly high frequency. However, in Massachusetts, where Gravity Tractor showed up as a choice on the voting sheet for the main scenario descriptions (2A and 2B), they chose Gravity Tractor at a much higher frequency in the "Other" category during the hypotheticals (i.e., for hypothetical 2A-1: MA = 92.6% vs. AZ = 58.3%, Table 4-4). Perhaps as a result, Arizonans, became more creative with their "Other" votes.

Table C-2: Thematic rationales given for favoring kinetic impactors in scenario one (4-year impact).The number in the right column is the number of individual responses that fell under each theme. (KI = kinetic impactor)

	Theme	*# RES.*
1)	*KI multiple plans* - Participants favored kinetic impactors as one part of a strategy that would employ multiple technologies	20
2)	*KI appropriate* - Participants felt kinetic impactors were the appropriate technology choice given the details of scenario 1.	17
3)	*KI timeframe* - Participants felt kinetic impactors would work given the time to impact specified for scenario 1.	13
4)	*KI first* - Participants felt kinetic impactors should be tried first before the other methods.	12
5)	*KI less controversial* - Participants felt kinetic impactors were less politically controversial and could be deployed more quickly given this than could nuclear weapons.	11
6)	*No nuclear detonantions* -Participants did not want to resort to nuclear detonation and selected other options, favoring kinetic impactors.	10
7)	*KI readily available* - Participants felt that kinetic impactors are readily available to use based on the details of the scenario.	6
8)	*KI risk* - Participants felt that kinetic impactors would be less risky than other technologies.	6
9)	*KI safest* - Participants felt that kinetic impactors would be safer than other technologies.	6
10)	*KI tested* - Participants felt that kinetic impactors have been tested and proven and therefore should be used given the details of the scenario.	6
11)	*KI effective* - Participants felt that kinetic impactors would be most effective given the scenario	4
12)	*Preventing impact* - Participants felt that everything should be done or tried to prevent an impact on Earth, favoring kinetic impactors.	4
13)	*KI minimizes nuclear failure* - Participants felt that KI could be used to minimize failures in the deployment of a multi-pronged strategy that include nuclear option.	3
14)	*KI research* - Participants felt that KI would give the opportunity to gather data and further research into more effective strategies for mitigation.	2
15)	*No response* - Participants did not give a rationale.	2
16)	*KI economic* - Participants mentioned economic considerations for favoring KI.	1
17)	*Too many choices* - Participant commented on the methodology of the dialog for mitigation and believed there were too many hypotheticals.	1

Table C-3 - The mitigation options that participants voted to enact in Massachusetts, Arizona, and both sites combined given a "4-year impact" scenario where an object between 25 and 100 meter in diameter has a 75% chance of impacting Earth. Note: Percentages don't add up to 100% because participants could choose more than one mitigation option:

Mitigation Options (“4 year impact”) Probability of Impact = 75%	***Massachusetts (n=86)***	***Arizona (n=97)***	***Combined (n=183)***
No action	1.2%	6.2%	3.8%
Civil Defense	80.2%	69.1%	74.3%
Kinetic Impactor	68.6%	63.9%	66.1%
Nuclear Weapons	60.6%	53.6%	56.8%
Other	12.8%	8.2%	10.4%

Table C-4 – Based on the "4-year" impact scenario, the percentage of votes that each Guardian type received in Massachusetts, Arizona, and both sites combined. Note: Percentages add up to more than 100% because participants were allowed to vote for more than one type of guardian.

Guardian	***Massachusetts (n=86)***	***Arizona (n=97)***	***Combined (n=183)***
NASA working alone	23.2%	13.4%	18.0%
A new US office of Planetary Defense	20.9%	18.6%	19.7%
The US leading an international partnership	50.0%	50.5%	50.3%
An international consortium that includes NASA	59.3%	63.9%	61.7%
Private industry	12.8%	8.2%	10.4%
International scientific/academic community	30.2%	3.1%	15.8%
Other	11.6%	1.0%	6.0%

Table C-5 The mitigation options that participants voted to enact (both sites combined) based on four different hypotheticals based on the "4-year impact" scenario. Note: Percentages don't add up to 100% because participants could choose more than one mitigation option (N=183 participants for all scenarios).

Mitigation Options "4 Year Impact Scenario"	**Probability of Impact = 75%**	**Probability of Impact = 25%**	**North American Impact**	***Global Catastrophe (Asteroid 500 to 1,000 meters diameter)***
No action	3.8%	6.0%	1.1%	4.9%
Civil Defense	75.5%	72.3%	77.0%	60.6%
Kinetic Impactor	66.8%	62.0%	62.5%	41.8%
Nuclear Weapons	56.8%	41.0%	65.0%	85.8%
Other	10.4%	10.9%	5.5%	9.3%

Table C-6 – The mitigation options that participants voted to enact, both sites combined given the "20-year impact – Continental Scale" scenario. Note: Percentages don't add up to 100% because participants could choose more than one mitigation option.

Scenario 2A "20 Year Impact - Continental Scale"	***Scenario 2A 50% Impact***	***Scenario 2A-1 10% Impact***	***Scenario 2A-2 North America***
No action	**22.2**	**21.1**	**1.1**
Civil Defense	**43.3**	**44.4**	**46.7**
Kinetic Impactor	**60.0**	**48.9**	**58.9**
Nuclear Weapons	**73.3**	**41.1**	**75.6**
Other	**37.8 (66.7)***	**56.7**	**47.8**

*For the initial scenario 2a description, Gravity Tractor was presented as an option only at the Boston forum. In Arizona, participants wrote in Gravity Tractor in the "other" category at a comparable frequency to what Boston participants voted for Gravity Tractor. For Scenarios 2A-1 and 2A-2, Gravity Tractor was not presented as a voting option in both Boston and Arizona. However, participants at both sites wrote Gravity Tractor in the "other" category at a high frequency (see Table 4.3 in Section 4).

Table C-7 – The mitigation options that participants voted to enact, both sites combined given the "20-year impact – Planet Killer" scenario. Note: Percentages don't add up to 100% because participants could choose more than one mitigation option. **[Gravity Tractor not an option – Note that many wrote gravity tractor down under "other"]**

Scenario 2B "20 Year Impact – Planet Killer"	***Scenario 2B 10% Impact***	***Scenario 2B-1 50% Impact***	***Scenario 2B-2 50-100 Years Away***
No action	**6.4%**	**6.4%**	**14.9%**
Civil Defense	**40.4%**	**42.6%**	**24.5%**
Kinetic Impactor	**47.8%**	**43.6%**	**42.6%**
Nuclear Weapons	**70.2%**	**74.5%**	**39.4%**
Other	**26.6% (43.6%)***	**37.2%**	**66.0%**

*For the initial scenario 2B description, Gravity Tractor was presented as an option only at the Boston forum. In Arizona, participants wrote in Gravity Tractor in the "other" category at a similar frequency to what Boston participants voted for Gravity Tractor. For Scenarios 2B-1 and 2B-2, Gravity Tractor was not presented as a voting option in both Boston and Arizona. However, participants at both sites wrote Gravity Tractor in the "other" category at a high frequency (see Table 4.3 in Section 4).

Table C-8: Example Individual Voting Results for Scenario 1

Participant	No Action	Civil Defense	Gravity Tractor	Kinetic Impactor	Nuclear Weapons	Other	What were your primary reasons for your recommendation?
1.1		x		x			1. Warning the public should always be a factor. 2. I chose kinetic impactors over nuclear because the risk of danger to human life is lower and nuclear can be the last resort.
1.2		x			x		Ethically, civil defense/preparation is a must. Despite a possible panic there need to be an informed public. Nuclear weapons seem the most effective and they are much more readily available over kinetic impactors, giving us more attempts if needed.
1.3		x		x	x		If the known location (approx) of where the asteroid will hit earth, I would recommend putting the most emphasis on civil defense - relocating citizens within 1-2 years of impact. If kinetic impactors have been tested and worked well in testing I would prioritize using them - if the asteroid was to be targeting a major city, I would have the nuclear weapons in place to be used.
1.4		x		x	x		I feel a combination of all the above would be appropriate.
1.5		x		x	x		I would use kinetic impactors immediately, assuming they are readily available. This way if anything unexpected occurs, the nuclear weapons are still an option. Civil defense is a great policy to implement as long as the information is controlled to prevent more panic.
1.6		x		x			Something should definitely be done about it by nuclear weapons is very drastic and risky, so kinetic impactors are a good option. Civil defense should be done regardless of what other option we pick as a back up.
1.7		x		x	x		I think that civil defense would be necessary as an option no matter what. (illegible) the 4 year mark prepping police/fire/med teams for potential impact would be important, but not broadly warning public yet. I'd also send out kinetic impactors to deflect. Should those fail, I'd use nuclear weapons. If that fails begin evacuating potential impact area. I think this would need a several month warning.

Appendix D – Asteroid Redirect Mission Results

(Data not reported in main body of report)

To best understand these results, first see a description of the questions and deliberation format discussed in the appropriate section above.

Table D-1 – Qualitative group rationales for support of ARM B. The first column indicates recurring themes found in group rationales. The second column contains specific participant rationales that correlate with the themes.

THEME	INDICATIVE GROUP QUALITATIVE RATIONALES
CONTROL - APPROACH GIVES BETTER CONTROL OVER SELECTION OF ASTEROID TYPE. BETTER CONTROL OVER UNKNOWN FACTORS ASSOCIATED WITH THE MISSION	The "control" factor that you would have for the following: planetary defense, scientific research, and eventually the opportunity to explore Mars.
	More control over composition of the asteroid - less risk of the chosen object being rubble hence less risk of misspent funds
	Scenario B -Higher probability to select object of desire -Learning/practicing landings -Practice/development of gravity tractors abilities -Ability to return to same object -Harvest resources
	Scenario B
	Chance of getting an accurate sample
	Choice A is too random
	Mechanically more efficient, developing area of funding by eliminating F35
	Greater accuracy of sample
	More definitive understanding of asteroid before taking sample
	Pushes the technology envelope
"COOL" - THE APPROACH HAS THE BROAD APPEAL	It is "cool" but rocks should be brought to Earth to examine. Better for proving ground, better for planetary defense. We didn't think plan A was good use of resources. These options don't seem to correlate all that well with the morning's goals.
	1) more bang for the buck 2) expands our capabilities more 3) advances planetary defense options 4) better for future explorations 5) way "cooler"
	Scenario B
	B encompasses all of the these especially planetary defense and quality of samples and it develops more technology before going to Mars. And it was cooler and more complex.
ECONOMIC - THE APPROACH COULD YIELD ECONOMIC BENEFITS	Technology: gravity tractor has important future implications. Potential of exploring economic benefits/opportunities of asteroid mining. Recent Rosetta success (landing) increases likelihood of success. "Cool".
	Scenario B

	Demonstrating planetary defense and technology. The economical potential of asteroids. Also the advancement of technology.
NEAR TERM BENEFITS	Short term success to satisfy future missions. This would make a number of things easier. Seems leading to B. Don't understand to question. 2[???] different. Asteroid mitigation. Proving Ground in general
USES/BUILDS ON PROVEN TECHNOLOGY	Technology is already available. Being able to determine the composition of larger asteroids in advance to benefit research + science. Planetary defense. This can also help mitigate asteroids headed toward earth. With good PR, this option can be 'cool'. This option allows for gravity tractor demo. Scenario B Building on demonstrated capabilities Multiple targets Can test new technologies this way You can play multiple versions not just snatch and grab Option A isn't credible and very difficult
PROVING GROUND - THE APPROACH RELATES MOST CLOSELY TO THE PROVING GROUND STRATEGY	Learn more techniques + technologies to help with asteroid risk mitigation It will be able to perform real time investigations of larger asteroids/objects. Similar to the moons of Mars. Our group believes that option B includes a wider range of the activities NASA is looking to pursue in the future. The on-asteorid maneuvering is more relevant to Mars exploration. While the stronger gravity tractor demonstration contributes to the mitigation research Advancing tech: B. Demonstrating Mars: A. Defense: B. Economic: B. Safety: B. But A is cooler. Scenario B Retrieval of smaller boulder from large asteroid with robotic arm Would have more benefit in future tech to go to Mars, less risk of failure, would be easier to collect and bring back the asteroid, more defense applications. [We recognize that] Scenario A has benefits of being "cooler" and being useful for cleaning up space junk, mining an asteroid or having more mass to sample, but it is riskier because it could just be rubble. Scenario B More logically explained; gravity tractor and phobos 4 diemos proving grounds /interesting. Better scientific data from sample. Scenario B Human exploration, advancing technology, planetary defense, engineering problem-solving, resources, going to Mars as stepping stone. Scenario B Gravity tractor and boulder capture; more relevant as proving grounds; object characterized beforehand. Questions: What if boulder is not solid? Or attached? Does this help us understand smaller asteroids better? Can option B be used for space junk?

Table D-2 - Qualitative group rationales for support of ARM A. The first column indicates recurring themes found in group rationales. The second column contains specific participant rationales that correlate with the themes.

THEME	INDICATIVE QUALITATIVE PARTICIPANT RATIONALES
DUAL USE - APPROACH IS PERCEIVED TO HAVE MULTIPLE USES	Scenario A: inflatable bag capture of ~10m asteroid We chose this so there would be a larger sample collected, advanced use of the ion beam technology, and we felt that there was a higher success rate. Space junk removal was possible. Allows private company involvement. Scenario A More material, space junk, side benefits
ECONOMIC	Scenario A For the economic potential gained from research; leveraging the economic potential for future technological advances.
LESS RISK - APPROACH APPEARS TO BE LESS RISKY THAN OPTION B	Scenario A (Demonstrating capability to go to Mars was NOT an important factor.) Advancing technology, less potential for failure, potentially larger sample/rock, less likely to encounter zombies

Table D-3 - Qualitative group rationales for lack of agreement on ARM A or ARM B. The first column indicates recurring themes found in group rationales. The second column contains specific participant rationales that correlate with the themes.

THEME	*INDICATIVE QUALITATIVE PARTICIPANT RATIONALES*
PRIVATIZE - EXPLORATION SHOULD BE LEFT TO PRIVATE INDUSTRY	NEITHER SCENARIO Challenging ARM capabilities strategy-leave to private industry Suggest other options such as moon colonization

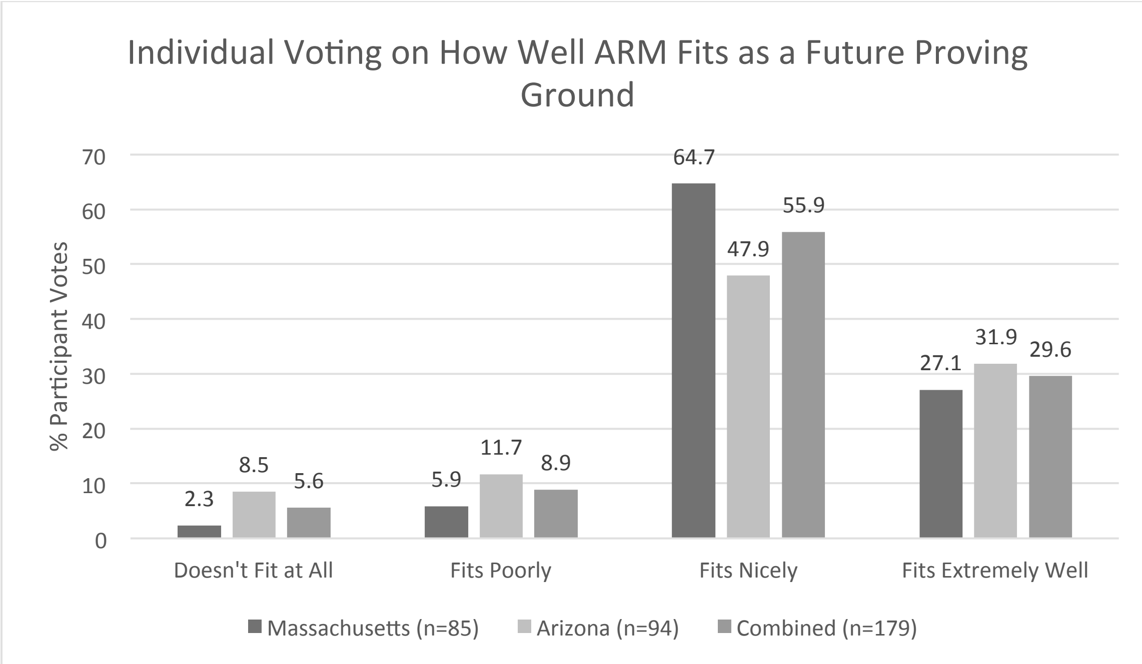

Figure D.3 – Participant voting patterns in Massachusetts (n=85), Arizona (n=94), and combined (n=179) on how well ARM fits as a future proving ground for deep space exploration. Once participants decided whether they preferred option A or B for ARM, they were then asked to respond individually to the following prompt: "Please rank the Asteroid Redirect Mission in terms of how well it fits with NASA's Proving Ground Strategy for future Exploration." The ranking categories were: Doesn't fit at all, Fits very poorly, Fits poorly, Fits nicely, Fits very well. We combined the "Fits poorly" and Fits very poorly" category for statistical analyses because the number of votes in these categories were very small. In addition to voting, individuals were asked to elaborate on their ranking selection in an open-ended response. (See Tables D-4 a-d in Appendix D for details) The majority of participants reported that ARM strategies "fit extremely well" or "nicely," citing reasons of fit with future missions; the development of dual use technologies; the trajectory to Mars, and economic efficiency. Those who felt ARM "fits very` poorly" or "does not fit at all" were interested in other exploration targets such as the moon or Mars. These individuals also felt the strategy was not logical or relevant to the proving ground, did not have enough information, or felt that the ARM mission was too costly for the projected outcomes.

Text Box D.1 Example of Qualitative Responses ARMS A vs. B Choices
(All responses not included here due to space constraints)

Sample Rationale Given for ARM Option A (italics added by the authors to emphasize interesting details):

- Mini deep space mission would be beneficial.
- **Proof of concept** for multiple important future considerations
- It will provide a larger sample asteroid for study, **less complex capture mechanism, ability to de-spin asteroid** would be scientifically valuable
- **Ion technology development**. Larger sample size. More control of collection.
- Appears to have less operations, which would trend to **higher probability of success**. Ion beam tech, possible more open to private industry.
- **More innovative in design**. Will become more valuable as time elapses.
- Larger sample - boulder may not be a good/complete representation of interplanetary matter (loss of hydrocarbons in collision)
- It seems **even with fail, more would be gained by attempting this procedure**. My concern with other option is "very" attached boulder.
- Get a whole asteroid rather than a small piece of one. Practical application of also collecting space trash in orbit around Earth.
- Scenario A allows us to take a larger sample of the asteroids. A single boulder may not be indicative of the materials and properties of its host asteroid. **An entire one lets us have a larger sample until we have a more focused research goal**.
- Smaller boulder in option 2 can be from another boulder and not necessarily able to give us the info for the "big 1". Also, love the idea of "cleaning" up the solar system.
- There's a **better engineering challenge with more technology development**. **Space junk is also as critical a threat as asteroid/planetary defense**.
- Bag may grab various asteroids and other debris. **Bag looks good and safer**!
- The **engineering complexity of this mission would be extremely beneficial to future missions**.
- Economic value, scientific advancement, and practice managing large bodies in space to **prep for Mars**.
- I like the larger sample providing **more opportunities to develop mining/economic technologies and relieve environmental pressures of mining on over-exploited Earth**.
- The fact that more "junk" will be collected is great as it can lead to a new discovery.
- Economic funding; **Easier sell to public**; Private funds generation for future missions or technology.
- A whole sample will be taken to Earth for thorough study and research; **Less complicated and more valuable source of information**.

Sample Rationale Given for ARM Option B (italics added by the authors to emphasize interesting details):

- More scientific knowledge required with more science to be discovered. **The testing of the Gravity Tractor for future space endeavors**.
- Ability to **study an asteroid in its natural motion**. Testing of gravity tractor technology for future use. Advancement of technology - robotic grabber, landing, etc… for future use in planets.
- Possibility of testing the gravity tractor
- Scenario B I believe would **yield more success, in the long run would/could collect more data and increase Mars exploration**.
- Better likelihood of overall mission success will demonstrate and **provide proof of technology needed for future deep space missions**.
- It would **provide more for human exploration** by allowing gravity tractor demonstrations
- Seems like we can collect better asteroid data and Mars' rover practice.
- In the long run this scenario will **help mankind with research**. Moreover, the research could save the world from a global killer.
- Cost and safety
- I think the data you can collect is compounded greatly with this option.
- there is **less risk that I can see and there more data that can be collected** from option B.
- 1) Redirect Course 2) Study composition of asteroid
- More control and application to the gravity tractor
- Seems more logical to handle or manuver the situation.
- Scenario A sounds cooler, but B **sounds more practical**. Without clarification, both sound like there's little connection to landing on Mars.
- Manipulate a larger object to gain a smaller boulder could give more overall experience in 2 ways, where (A) only caputres a smaller one.
- Proves **more re-usable technologies faster**
- It will use the gravity tractor to allow us to mine for a suitable boulder
- Demonstrate technology, science, **proving ground for Mars (Phobos and Deimos)**, demonstrate defense tech, bolster public interest
- Better results ions term. Asteroid = piece of asteroid, whereas space junk ≠ asteroid.
- It has greater potential to advance technology and can lead to greater benefits.
- **Essentially demonstrates a "mining" operation while proving out gravity tractor and refirming our capability to capture and land on an asteroid sized body**.
- It has more potential benefits for providing asteroid defense and may provide more

Table D-4a&b - Qualitative individual rationales for the favorable rankings of how well they feel ARM fits with NASA's Proving Ground Strategy for future Exploration. Column headers indicate the ranking categories "fits nicely" and "fits extremely well". Column data contain specific participant rationales associated with each category, and multiple columns are used to save space.

(a) Fits extremely well	
All that will be learned from this will be material for future experiments.	What better than to study the composition and history of an actual asteroid?! It is a great tool! It is "cool"!
Any new technology needs a close range test to work out bugs. This would be the best option to experiment in developing the technology.	It will further space exploration.
Because of #2 above	It will provide many data points for any future space mission.
Because there is lots of creativity and insightfulness that can come from "B"	Makes more sense to achieve objectives on our way to landing Mars.
Because there's multiple techniques and technologies you can test for other missions including "A" and Mars.	Many possible applications could be developed out of the proving.
Both provide opportunity to gain new info and test new technologies.	More research and understanding of the object.
Both would be extremely useful for the future (such as Mars, etc).	NASA is about advancement of exploration through known technology and advancing its capabilities
By watching NASA TV	Provides further exploration and research.
I am only thinking in terms of testing potential planetary defenses, which I regard as highly valuable. This tech requires testing.	Several different types of data can be retrieved
I chose this ranking because I believe that it has various factors that can be tested - such as gravity tractor.	The craft will land on a body, then take off from it.
I feel it falls in line with the direction of NASA's future exploration.	The exercise is of learning primitive skills that are essential to future.
I think all the technology testing that we'd do for option B it lends itself naturally to further space exploration, while protecting the planet.	The knowledge gained may allow for NASA to apply to MARS and other entities.
I think opportunities to develop mining/economic potential of asteroids will help the Earth's environment.	The mechanism and strategy are extremely similar to Mars rover tactics.
If NASA is successful on this mission it would gain more trust and respect globally in trusting NASA with an essential role on planetary defense.	The NASA work very good
If the goal is to try to accomplish multiple goals w/ these missions, both options fit this extremely well. We stand to learn a lot about potential next steps.	The technology to be able to further space exploration should be the driving force for these missions.
It advances our ability to maneuver in space.	These sort of practical/commercial/public value missions are what I find most beneficial to everyone.

It fulfills the objective of accomplishing a useful task that will also provide information and training for future missions.	This project not only helps with planetary defense but also advances multiple types of technology and strategies for space exploration.
It has been proven by recent events to work.	This redirect mission of the boulder will allow us to demonstrate that not all missions need to have an end date. Missions can be continuous and evolving.
It is a stepping stone, a technology development exercise for future missions.	Tries out several new technology approaches. Test of new propulsion and now mechanical space systems.
It is an incremental step toward earth independence	Use demonstrates the possibility of asteroid mining, (illegible), and take off - landing.
It is creative and innovative and test new technology for new frontiers.	Very adaptable
It is designed to include a range of scientific, technological, engineering, and human exploration components to develop a range of concept areas.	We are developing the technology needed for such venture
It represents a stepping stone toward larger discoveries and will prompt more interest in the field of astronomy/astrophysics	We are discussing the options of future exploration
It seems to try out landing and taking off from small objects and testing the gravity tractors	we can land on an asteroid and do have control/freedom to collect scientific data and research new technology methods to help us pave the way for colonization and Mars.
Whatever findings/result we get from this will be very helpful for future exploration of Mars.	

(b) Fits nicely	
Accords with NASA's budget uncertainties	If the landing on Mars' moon - a possible asteroid - is the mission of NASA's ground strategy
Appears to be realistic	It advances the science and the technologies that will be needed in the future.
As it could provide more information on how to land in surface that have similar composition.	It all makes sense and connects well.
Asteroids are slightly different from planets. They are also smaller. So while testing with asteroids helps, more is needed for diverse exploration.	It allows training in retrieving boulders from planets' surface for analysis.
Baby steps	It allows us to determine larger asteroids that may damage the earth w/ higher degree of damage
Because I feel that NASA will be able to find relevant Mars related asteroids, which will help in understanding the composition of the other planets	It can provide new technology and data to be used in deep space missions.

Because it allows us to test out techniques that will be required in space exploration.	It could do nothing but help the cause
Because it fulfills some of the goals of the preparation o the ARM mission as well as some of those of the Proving Ground Strategy.	It does seem like it can help planetary defense.
Because it will be using the G.T. method, which will prove useful for future explorations.	It enable new learning of the practices and knowledge needed for space missions.
Because it will serve both getting to Mars *and* protecting planet from asteroids	It fits nicely with the proving ground strategy, but does not seem to be incredibly valuable to mitigating large asteroids as previously discussed.
Because landing on space structures have been proven.	It is clearly relevant, but not with regards to human survival or the shuttle trip to Mars.
Because Scenario B will have better results.	It seems like a logical next step from the Apollo missions.
Because the techniques used would be useful in a Mars mission and an asteroid gravity tractor mission.	It seems like something that would help in understanding space more. Therefore, furthering exploration. It is an opportunity to learn about different material in space.
Because this demonstration will allows for future exploration of Mars and other planets	It seems like there are many more pieces that would help with Mars
Because we can use the same technology to "grab" boulders from Mars.	It will be a good place to try new technologies, but the resulting science from the asteroid could be gotten in other simpler (like not having to park it around the moon) methods.
Because we would get to try gravity tractors which could help in the case of an imminent asteroid impact	It'll help us test options for dealing with threats to Earth from asteroid impacts.
Building for future exploration	It's doing new stuff.
Capturing asteroids and practicing deep space missions is relevant to exploration	Most helpful to mass mission
Could be helpful in developing and refining strategies for future exploration	NASA is doing a good job
Data gathered from ARM provides a springboard for future NASA operations.	NASA needs to head towards much more incremented missions. This fits that nicely.
Definitely valuable; Only hesitation is that we've also landed and retrieved nodes on the moon and Mars; maybe we already "know how" to do this	Not sure
Demonstrates multiple capabilities in a singular mission and success or failure one capability doesn't always compromise mission capability of other purposes.	Nothing's completely set in stone and could change so "extremely well" is pie in the sky at this point.
Develop technology for future missions; Also can practice mitigation.	OK, alright... Not convinced it is all that necessary right now.
Does fit into NASA structure with private industry applications.	Practice landing; opportunity for off-Earth mining related to Mars return.
Does sound like a good step to further understand asteroids	Provides many options for knowledge for further exploration - Mars
Either mission will further develop interplanetary flight.	Provides safety. Serves to the purpose of the space mission. Helps to make decisions on future space travels.

Either option certainly leverages potential, investigative opportunity. MUST keep moving the boundaries of our space and technological frontier.	Proving Ground Strategy can be inefficient because money is spent on diversionary or unrelated technologies, not on critical path to Mars. Efforts need great focus, not technology standby.
From moon/orbit based is not the same as from asteroid landing/takeoff	Samples from the asteroids are what will be used for future exploration and findings.
Further understanding of asteroids	Seems design is flexible to other applications
Gain knowledge in moving objects in space; captured asteroids are a lab for further testing	Seems like the most logical plan with greater opportunity to gather data
Gathering information that would aid in the future	Seems to benefit strategy's well, and could be followed up with many other missions that would "build" on it.
Given that we are looking to explore deep space or other planets it would help to harvest and develop/manufacture in space	Sending astronauts to the captured asteroid seems to fit well with the possibility of sending astronauts to the moons of Mars.
Gives permanent testing location closer to earth, a source that can be reused indefinitely. May reinspire further missions to get humans in space	Some risk, but nice chance of success
Good practice for testing multiple techniques for future missions. However, I feel as though practicing setting up stations on the moon and testing out manufacturing methods in a low gravity setting would bring more value when performing a longer distance mission where resources and help are far away. We have the moon extremely close as essentially our "playground" to practice techniques and technology on in a low gravity environment, so why not use it to develop our space vehicles and reserve bases. could expand to growing food in space, etc etc etc. Although, using the moon as our main proving ground would not help with asteroid redirection.	Sounds appropriate
Good way to test new ideas and technology before becoming mission critical	The ability for astronauts to work on the returned asteroid would apply to NASA's proving ground strategy by showing the ability of astronauts working in space.
Great steps towards space exploration and into the unknown.	The landing on the asteroid is part of the moon for Mars, similar application use.
Hopefully safety	The whole point of the Proving Ground Strategy is to develop a method and create a stepping stone to exploration on Mars. What better way of practicing than on an asteroid.
I believe that it is important to known your parameters rather than learn the hard way.	There are more important auxiliary skills being tested.
I believe that there should be more options	There should've been a "fits somewhat" since it needs to be more targeted to the final direction.
I can see somewhat about how it fits, but I'm not sure I see its exact role.	There's always room for improvement.
I chose this because I feel like it is a stepping stone to help get there.	There's always the chance - the 1st step won't be successful - That will be good to know now, though. Get working on many solutions sooner.

I feel the ARM is a stepping stone to ground strategy for future exploration	Today's technology can handle these conditions
I think anything that fits with benefitting space exploration and the understanding of space, fits with NASA's proving ground strategy.	Trying to do several things in 1 mission is more cost effective. Engineers need to think bigger/broader than 1 end goal.
I think it could fit better. It feels better suited to learning about big asteroids for defense reasons, but it allows us to practice landing on and collecting info about more outer space objects & getting to a far away object (propulsion).	Use of resources and technology
I think it fits well because it's a stepping stone to getting to Mars. I thought this question was worded poorly. The two missions were given and the "first major proving ground mission(s)." Of course they fit well. If we choose that it doesn't fit, what's the other option or reasoning?	We can extract a lot of information about asteroids and where come from (in terms of the universe) that will be relevant to future space exploration and discovery.
I think it's a great idea for Mars. It fits good.	I think the techniques and technologies necessary for this mission will be perfectly aligned with those needed for a "proving ground" mission.
I think that this may be a reasonable solution to asteroid issues.	Ideally multiple simultaneous options would be implemented.

TableD-4c - Qualitative individual rationales for the unfavorable rankings on how well they feel ARM fits with NASA's Proving Ground Strategy for future Exploration. Column headers indicate the ranking categories "Doesn't fit at all", "fits very poorly", and "fits poorly". Column data contain specific participant rationales associated with each category.

Doesn't fit at all	**Fits very poorly**	**fits poorly**
Asteroids are a terrible analogue for Mars. Negligible gravity, different composition/surface operations, different challenges to astronauts. ARM is a detour to Mars. Lunar surface missions would be a better pathway for proving grounds.	Because of the uncertainty of the security	(Between poorly and nicely) The tech advancement would be helpful, but in terms of the human element in exploration, it doesn't quite fit well.
Because it doesn't add up or make sense	I don't think it demonstrates long term space flight, which is necessary to reach Mars. It does, however, provide a proving ground for planetary defense.	I feel like NASA is more worried about other projects than the Asteroid redirect mission.
Don't see the relevance	I think it's proving very little in the ultimate mission to the planet Mars. It seems like a very expensive way to just "practice".	I think option A is better for future exploration endeavors due to the size of the specimen obtained
Go to the moon. The moon is our proving ground! ARM is a pissing contest!	I've read articles talking about how completely unrelated asteroid captures are to Mars manned missions.	It seems unclear how it fits
I feel we need to create tools for deflecting asteroids as mentioned earlier, but we don't need them for proving grounds.	Its immediate application to a mars mission or otherwise is not obvious. I don't quite see the connection.	NASA could be more productive and colonize something.
This has nothing to do with landing/living on Mars. This has everything to do with defense against asteroids and mining asteroids.	Not enough choices of technology, it seems in this program of mitigation to save so many lives, more options should be on the table (technology)	Overall, Scenario A appears easier and not really pushing the technology as hard as option B.
	Not really sure I understand the two benefits	Studying the captured asteroid fits, but capturing it may not. Seems pretty fundamental research. Important but not as relevant as it could be.
	Spend billions of dollars to actually colonize a relevant environment; don't give me this asteroid crap! It proves very little. Grow some balls and be ambitious for once! China will colonize the moon; let's do it first to slow superiority and raise national pride!	The relationship between dealing with asteroid threats and a proving-ground approach toward a mars mission seems unclear.

		The way I feel.
		Use the moon as proving ground
		Where's the neutral choice here? Not sure what the "redirect mission" is all about. Do you mean by redirecting all the asteroids and what is learned from these missions, it may help NASA, then this is probably true.
		With moon exploration, we already now how to land on a predicable, moving object. Unless the asteroid is made of a similar compound to Mars, I don't see ARM helping space exploration anymore than what we know from moon landings.

Box D.1 – Further analysis on whether the Proving Ground frame unduly influenced participant choices for Option A or B.

The initial question to decide between Option A and Option B did ask which approach made sense given the Proving Ground approach. We do not believe that the presence of the "Proving Ground" frame in the ARM preference question affected the results. In the written rationales, participants did not refer specifically to a "proving ground strategy", but instead cited individual issues with varying degree of frequency. Review of their reasons for selecting option A or B in the individual voting sheets show that a multitude of issues were used. These issues were drawn both from the presented scenarios and the proving ground strategy, but also from other portions of the day's discussions, media reports and information materials. In the case of the ARM Option A vs. B session, participants certainly considered the options through the "proving ground" frame, but independent rationales also emerged. First, consider how often participants used the concept "proving ground" in constructing their group and individual rationales during the ARM Option A vs. B session. The following numbers were derived from individual and group rationales from voting responses during the ARM Option A vs. B session. In total, the concept "proving ground" was used by five groups (AZ = 3, MA = 2, Total Number of Groups = 27) in constructing the rationale for their choice. Individually, a total of 11 participants (AZ = 7, MA = 4, Total = 183) used the "proving ground" concept in constructing their rationale. Instead of structuring their responses specifically in relation to the proving ground strategy, individuals often focused more on concrete/tangible reasons for choosing Options A vs. B (see Table 5.5).

Appendix E – Mission Planning and Journey to Mars Results

(Data not reported in main body of report)

To best understand these results, first see a description of the questions and deliberation format discussed in the appropriate section above. Results begin on the next page.

Text Boxes E-1 Example Qualitative Responses on Mars Scenario Choices. All responses not included here due to space constraints.

Sample Rationales from voters for Orbital/Robotic (crew in orbit with expanded robotic missions) – italics added by the authors to emphasize interesting details:

- It seems like there is a lot to **learn from this and then NASA can create mission priorities** from there.
- Safer; Less expensive. **Would more specific $ details before I move to a colony.**
- Most fiscally responsible option. The engineering required to send infrastructure for other options seems unfeasible.
- **I don't think we should move onto the viking or pioneer approach until we know we can travel that far through deep space in the first place.**
- A robotic exploration with a manned control in a nearby moon could set the precedent and build the scenario for the implementation of a future Mars human settlement
- This makes the most sense to me as a reasonable target. Robotic exploration will give us more information sooner, which could be used to further our explorations (as long as we are inclusive in our opportunities)
- Can be implemented quickly, low cost, less risk to human space travelers.
- **Baby steps**
- Doing all three in a sequence gives the opportunity to estimate and attempt to mitigate the risk to humans in a manned mission. The viking strategy will provide additional opportunity to assess risks for a long-term human settlement. Also, I would suggest a manned trip to the moon before the viking strategy. **A viking mission to the moon**.
- Budgetary reasons, human liability and the technology (current) will limit a long term future of Mars exploration. I believe the robotic exploration will be a better choice when allocating funds to explore the planet (Mars) and get a better understanding of how to permanently settle a colony.
- Need continued and expanded robotic exploration before any crewed exploration. Right now, we don't have the technology to safely or effectively send crew.
- Although I want to support human exploration on Mars, I am unsure of the moral and ethical validity of creating inter-planetary colonies. Any strategy needs a great "big picture" engagement strategy for public support.
- I agree space and Mars exploration is important, especially for encouraging and fostering the drive of scientific advancement and scientific creativity, **but I feel it is selfish to consider further exploration when there are so many issues** and concerns present that are so pressing and urgent in our world.
- Since there is no life in Mars, not necessary to send human body there.
- Robotic is a stepping stone to future Mars **- it will be less costly and faster.** Can establish colony on Phobus/Deimos as a staging area testing zone for future landing on Mars. Would get people excited about future colonies.
- More needs to be learned about the Martian environment and ways found to counteract the biologic negative before colonization (even by scientists) can be undertaken. Scenario 2 is too much like our moon race, from which nothing followed. **Next time, horse before cart.**
- Not enough data yet - "what if" unforeseen dangers exist
- It is cheaper and will give us more exp. **Safer to have men on the moons of Mars.**

Sample Rationales from voters for Viking (Short term mission) – italics added by the authors to emphasize interesting details:

- Vikings will have to use robots anyway and gives us better samples and information pertinent to deciding if a human settlement is even possible.
- Expense and I feel like there would be much of the same results.
- **I chose this because I want to see a manned mission to Mars but I don't see the point of the pioneer option from a fiscal standpoint.**
- Not clear on the benefits from a colony on Mars.
- Want to see [a] boot on Mars and the boot should be on a woman.
- Get people to Mars. Robots are boring. **We need the human scientists to collect the most data.**
- Safest, smartest, most productive choice.
- Danger to human life.
- 1 - already have had robots up there, so need next step. 2 - Better science can be gathered/collected. 3 - Again, gives us greater amount of science and difficulties to study after. 4 - Pioneer is too costly and robots are less interesting and scientific.
- **It's an acceptable middle-ground.** The trips to the surface would require advanced technologies; they, in turn, would make the pioneer approach possible if conditions on Earth require.
- **You must find out what will work and what won't and what is the best way to go forward after testing it on a small scale**.

Sample Rationales from voters for Pioneering (Permanent Settlement as Immediate Goal) – italics added by the authors to emphasize interesting details:

- **The viking approach may lead to the same disinterest** that followed landing on and then leaving the moon. Also, the Earth is reaching a carrying capacity, so we can use space and resources on Mars.
- **Not have all our eggs (humans) in one basket (Earth).**
- Human Earth independence. Advancing our proving ground farther so that we may move our frontier even further out!
- Go big or stay home! **Huge potential for collaboration with private industry.**
- I believe becoming a two-planet species is incredibly important. It is time to advance to that point. The benefits of a permanent settlement greatly outweigh the cost and risks.
- Colonizing another planet will be important for our civilization in terms of learning about the possible future of Earth and own solar system as a whole.
- **The human experience** of living on Mars, a human waking, living, solving problems, writing poetry, making art, yearning for Earth make colization, the risks and costs seem trivial. Robots don't love Mars or Earth.
- Because it's awesome! Make the solar system seem smaller, get human eyeballs seeing Mars and science excitement, future social impact and technological advances will follow. We should do this regardless of the cost.
- So much innovation and discoveries waiting to be made! Incredibly expensive and ambitious, but in encapsulates the human spirit.
- **Single point failure** - if humans only live on Earth, they are less likely to survive than if humans live on multiple planets. Human exploration of Mars will increase public awareness of space, and it seems like the penultimate goal of human to spread to other worlds. **We should terraform Mars!**
- **Go big or go home:** I don't want interest to be waning in the program after a viking type mission. It comes down to who our ultimate question is, **why do we care about Mars?**
- We will learn more by actually doing.
- The possibility that we might go to Mars and then leave like the Apollo missions seems unacceptable to me. It just ends up being a waste of resources and is reduced to nationalistic pride. There still may end up being significant value/economic value as we turn to asteroid mining.
- We've been robotically exploring Mars for 45 years. It's high time we started sending people. Money is a human construct, it should not dictate our futures.
- Robotic: we **don't need real time telemetry** - waste of money, if you're going to Mars orbit, just land on it! Invest in better autonomous robots! Viking: I push for lunar colonization for profit: asteroid mining for profit - use this for Mars since I don't see any economic benefit for Mars colonization. Pioneer: Go big or have everyone lose interest really fast - this should be done after **lunar landing** and would serve as good practice for exo-planet colonization.

Sample Rationales from voters who did not embrace Mars exploration generally – italics added by the authors to emphasize interesting details:

- None of the above. I don't really see Mars exploration as worthwhile on the whole. I think it's worth it to test our technological limits and take actions to be about to travel and explore further. **I don’t get the motivation for exploring Mars more. What could we learn that we don't know from rovers? I think evidence for life is a huge motivation for the public, but I don't see that with Mars.**
- I agree space and Mars exploration is important, especially for encouraging and fostering the drive of scientific advancement and scientific creativity, but I feel it is selfish to consider further exploration when there are so many issues and concerns present that are so pressing and urgent in our world.
- Since there is no life in Mars, not necessary to send human body there. It is not worth since **no one around our discussion table wanted to go to Mars.**
- (NONE) **There wasn't a real goal as to why we should go to Mars** when there isn't enough technology to support a comeback trip and specific outcomes other than it is new. **Proving Ground strategy seems better.**
- This will provide info needed for the other two types of missions. Frankly I have a hard time supporting the idea of deep space exploration while **there is so much that still needs to be done on Earth to solve the problems of resources to sustain life on this planet.**
- Manned exploration is too **expensive**

Text Boxes E-2: Example Qualitative Responses on Whether Public Accepts the Proving Ground Strategy (which was a proxy for the Capability-driven Framework)

Sample Rationales from those who said Yes, they approved going forward with the Proving Ground Strategy. Italics added by authors to highlight interesting details.

- **Seems like the logical way to go about undertaking such a monumental task - in small steps, proving necessary technologies and techniques along the way.**
- The strategy outlines multiple important technologies that will be very important on the way to Mars.
- **It makes sense to learn to walk before you try to run and to be efficient and not waste resources and efforts and time.**
- We need to perfect and develop the technology before we can effectively explore Mars or the rest of the solar system.
- Proving Ground strategy let you analyze step by step how to logically proceed.
- **Limited budgets at this time. Much can and will be accomplished with pragmatic logistics.**
- **Rational. Reflective of our current political/economic times. Concerned it might truncate or constrain the full potential of Martian investment (ie succumb to political change…)**
- **If a plan is laid out and a step isn't arrived at on time, human interest is lost because they will doubt the whole plan will be completed.**
- Moving forward with Mars colonization, in incremental proving ground steps, seems feasible, logical, and crucial.
- Cost-effectiveness and I truly believe that we need to focus on one thing at a time to understand the next thing.
- Possibility
- **Hard to get funding for a big project. Easier to get funding for smaller projects with short-term goals that are attainable.**
- I love advancements in science. The proving ground could be adjusted as our ideas and needs change.
- Not really sure, but sounds like a good idea.
- **Logical to move in smaller steps to develop new goals**
- We need to do this so generations to come can benefit out of it.
- I think the proving ground strategy would set the ground work to achieve Mars exploration.
- **I like the idea of trial and error** instead of a step plan of full force mars exploration. If the asteroid plan works, then people would be more willing to support the Mars plan.
- **Practice makes perfect.**

Sample Rationales from those who said they were Unsure if they approved going forward with the Proving Ground Strategy. Italics added by authors to highlight interesting details.

- It seems to be a primitive, yet it's working thus far. **I think it's like a bandaid that's been working for so long.**
- **I fear that any step in the process people could lose interest/pull tax funding and therefore going to Mars immediately would be better.**
- I support it, but I desire accelerated scheduling/execution as it leads toward the "pioneering" scenario.
- The short-term projects allow for measurable progress/success. That is valuable when seeking funding or public support. I don't necessarily agree with long-term Mars colonization, though.
- I believe in the power of goals and milestones, but the scope of this project must be flexible to accommodate new advances in the available technologies.
- **I'm not certain that the proving ground strategy is specific enough**. It seems too regularly described for something so important and expensive.
- I'm just not sure.
- Too many unknowns. Need to prove many technologies, before manned Mars missions are possible. Need to demonstrate technologies in Earth orbit and on the moon.
- **Safety and expense**
- Not enough information
- Because it makes more sense to me to do the robotic exploration because it is more sensible and cost effective.
- **"Proving ground" can be inefficient use of money; many technical deadends or non-relevant experiments; could be "technology sandbox" if not focused/directed research.**
- **I like the idea as I understand it as I think it is responsive to what we many not yet know.**
- **Has room for improvement, but at least leaves room to cut your losses at any time towards the ultimate end goal. However, lack of motivation towards an end goal may lead to infficiency.**
- The proving ground strategy makes sense if each intermediate step builds towards longer-term goals. Too far on one side on flexibility could mean an endless chain of "successful" missions that don't advance toward a longer-term goal.
- I am not sure of any of this.
- **I'm afraid that piecemeal approach lacks accountability. It's easy to just give up.**
- I'm not sure how worthwhile it is. I think studying asteroids and how to manipulate them can be very valuable.
- Because it makes more sense to me to do the robotic exploration because it is more sensible and cost effective.
- **I feel that hard deadlines will have less (illegible) of losing public support like apollo did. It also removes the excuse of needing to look for the "right time" where funding and public sentiment align**.

Sample Rationales from those who said No, they do not approve going forward with the Proving Ground Strategy. Italics added by authors to highlight interesting details. All “no” rationales are included here due to the small number of results.

- Going to mars necessitates overcoming many obstacles to gather. These solutions can be applied to all kinds of space exploration. Get the asteroids threatening Earth first.
- **It is a distraction. Asteroids are a detour. And the lack of a true goal make the programs targets for lawmakers to cut.**
- **We need to proceed with Mars exploration now. We need a plan to begin mounting a human Mars mission, and need to begin implementing that plan immediately.**
- I think that we are starting to realize that Earth is vulnerable as is life as we know it, so we need to seek other habitats to thrive in.
- We need to keep moving forward, developing new technology, practicing in new scenarios. Having this "stepping stone" is important.
- I don't believe that this part of exploration is currently necessary.
- Politically motivated. Avoid the grand strategy.
- **NOT ARM!!! I support colonizing the moon first. It will be easier than Mars, cheaper, and has economic benefit. You can build a platform on the moon to launch to Mars.**

Box E.3 – An analysis of differences mission scenario choices between Arizona and Massachusetts.

Analysis of the qualitative responses given for voting choices provides some additional detail about the different rationales employed in Arizona and Massachusetts regarding the selection of robotic orbital missions versus landing on Mars (Appendix E, Table E-1). Massachusetts participants who favored the robotic exploration approach cited economic factors, benefits to research and minimizing risk to human life among the top reasons for selecting this option. They also felt that robotic orbital exploration is well suited as the first step in a staged exploration strategy that would include all three options. Others cited the concern that the current stage of technical development makes human spaceflight too risky. Another concern cited by four Massachusetts participants is that resources spent on space exploration should be weighed against tackling pressing issues on Earth.

Arizonans who favored robotic orbital exploration also most frequently cited economic factors as important. Like the Massachusetts participants, these respondents felt that robotic exploration is well suited as the first step in a staged exploration strategy, however written responses indicate that they see robotic exploration as a step towards human spaceflight and permanent settlement explicitly.

Tables E.1-2 begin to explain why Arizonans preferred human exploration over robotic missions. One of the most common claims among Arizona participants centered on notions of "Ambition" and the need to settle Mars, such as becoming a "Two-planet species." Some of the less frequent claims also center around ambition, including one person who was concerned about limited funding, who suggested that we should shoot for the "grandest frontier" (instead of spending money on incremental steps) and a participant that wanted a woman to be the first "boot on the ground." Whereas in Massachusetts, "ambition" is virtually absent among those selecting landing on Mars (Pioneer and Viking). Many of the Massachusetts rationales were more pragmatic and included robotic exploration in their rationales.

Two possible external factors contributing to the difference between Massachusetts and Arizona are: (1) Arizonans may be more inclined toward human exploration because they live in a "frontier" state where individualism and risk-taking are part of the culture, and (2) the deliberation was held on a university campus and included student participants, including some in science and engineering. Science itself has famously been called 'the endless frontier" (by former MIT Provost and Truman advisor Vannevar Bush right after World War II), and the love of exploration and discovery seems more likely to find expression in such a setting.

Appendix F - Pre/Post Survey Results

F-1 Participant Satisfaction with Organization of "Informing NASA"

Table F-1 – The mean responses on a scale of 1-7 (Absolutely agree = 1, Absolutely disagree = 7) of participants in both Massachusetts and Arizona combined to the following prompt in the post-survey (n=182): "Are you satisfied with the 'Informing NASA's Asteroid Initiative' event?" Note: Standard deviations are reported in parentheses.

Organization of the Event	*Mean Response*
1) The objectives of the whole event were clear to me.	1.49 (0.69)
2) The assigned tasks were clear to me.	1.43 (0.82)
3) The role definitions of all actor groups involved (participants, moderators, panel of experts, staff) were clear.	1.31 (0.79)
4) It's clear to me how the dialogue results will be used.	2.16 (1.38)
5) All participants had the same opportunities to voice their opinion.	1.20 (0.65)
6) Participating citizens had enough opportunities to suggest changes of dialog conditions if needed.	1.74 (1.17)
7) In the dialogues, I was able to contribute my ideas and views when results were developed.	1.16 (0.52)
8) Participating citizens were treated respectfully by the organizers (organizing team, moderators).	1.08(0.49)
9) Citizens discussed the topics constructively (ex: active listening to contributions, respectful treatment of others).	1.19 (0.60)
10) Diverse societal groups (ethnic minorities, age and income groups, etc.) were appropriately represented in the event.	1.73 (1.35)
11) The moderator(s) facilitated dialogues effectively.	1.39 (0.91)
12) Our moderator(s) supported a creative mutual exchange of arguments during the dialogue.	1.24 (0.71)
13) The background information I received sufficiently prepared me for the event.	1.61 (0.95)
14) Information about the topic provided by organizers was unbiased.	2.11 (1.46)
15) The contributions by other participants were useful.	1.40 (0.82)
16) There were enough opportunities for the citizens to sufficiently discuss and reflect on information and arguments.	1.39 (0.86)
17) Logistical arrangements for the event (travel, accommodation, meals, etc.) were appropriate.	1.46 (1.01)
18) The time management of the event was appropriate.	1.39 (0.94)
19) The event provided enough breaks and recreation time.	1.38 (0.78)
20) The event used my time productively.	1.35 (0.85)
21) Technical support for the event (equipment such as audio, computer, projectors) was appropriate.	1.41 (0.96)
22) I am fully satisfied with the event process.	1.36 (0.80)
23) I felt comfortable interacting with the experts participating in the event.	1.44 (0.94)
24) Experts responded to participant input in a way that I could understand.	1.38 (0.85)
25) The experts took participant input seriously.	1.41 (0.90)

F-2 Participant Assessment of Results (Post Survey)

Table F-2 The mean responses on a scale of 1-7 (Absolutely agree = 1, Absolutely disagree = 7) of participants in both Massachusetts and Arizona combined to the following prompt in the post-survey (n=182): "Please assess the results of this event." Note: Standard deviations are reported in parentheses.

Quality of Results	***Mean Response***
1) The outcomes of the event reflected my personal perspective on the NASA Asteroid Initiative.	2.02 (1.11)
2) Important issues brought up during discussions were not included in the final statements from my group.	4.63 (2.07)
3) There were no problems during the event that compromised the validity of the outcomes of my group.	1.53 (1.12)
4) The outcomes of the event should be circulated among political decision-makers.	1.62 (1.13)
5) I'm expecting that the outcomes from the event will receive significant attention from decision makers.	2.39 (1.58)
6) I am satisfied with the statements and outcomes developed within my group.	1.60 (1.00)
7) It's beneficial to continue conversations about the NASA Asteroid Initiative project in the future.	1.30 (0.84)
8) The event significantly increased my knowledge about space exploration and the asteroid initiative.	1.46 (0.90)
9) The event enhanced my understanding of alternative perspectives to my personal opinion on asteroid strikes and how the threat can be addressed.	1.60 (1.06)
10) The event made me feel that citizens' voices are relevant for policy makers in the field of space and science issues.	1.80 (1.15)
11) The event makes me want to participate in another deliberative process.	1.26 (0.90)

F-3 Interest and Knowledge (Pre and Post Survey Comparison)

Table F-3 - A comparison of the mean responses on a scale of 1-7 (Absolutely agree = 1, Absolutely disagree = 7) of participants in both Massachusetts and Arizona combined to the following prompt in the pre-survey (n=189) and post-survey (n=182): “How would you assess your personal interest and knowledge regarding the topic of asteroids and NASA’s future initiatives after participating in this event?” Responses that are significantly different at $p < 0.01$ (Paired T-test) from the pre-survey to post- survey are marked with an asterisk. Note: Standard deviations are reported in parentheses.

Statements about interest and knowledge	*Mean Responses PRE-SURVEY*	*Mean Responses POST-SURVEY*	*Statistical Significance P<0.01*
(1) It’s very exciting for me to get more detailed knowledge on asteroids and space exploration.	1.65 (1.13)	1.20 (0.49)	*
(2) I often talk with other people about subjects related to asteroids and space exploration.	3.02 (1.70)	2.96 (1.80)	NS
(3) There is no relationship between issues about asteroids/exploration and my everyday life.	4.53 (1.75)	4.49 (1.88)	NS
(4) In comparison with other scientific subjects, asteroids and space exploration are not the most important to me.	4.63 (1.66)	4.36 (1.77)	NS
(5) I feel I need more information in order to determine my opinion about asteroid issues.	2.80 (1.68)	4.09 (1.91)	*
(6) I feel I need more information in order to determine my opinion about space exploration issues.	3.20 (2.01)	4.03 (2.06)	*
(7) I feel confident when making comments about and judging NASA-related issues discussed during the deliberation.	2.99 (1.52)	2.33 (1.29)	*
(8) I am aware that asteroids that are 30-50 meters across, which can create about a 1 km crater, hits Earth on average every 1,000 years.	3.62 (2.12)	2.03 (1.52)	*
(9) I am aware that there is an international near earth object detection network in place around the globe.	3.14 (2.09)	1.73 (1.19)	*
(10) I know about the meteor strike that occurred in Chelyabinsk, Russia in February 2013.	2.49 (2.09)	1.23 (0.75)	*
(11) I am aware that NASA plans to test launch its new manned space vehicle, the Orion, in December 2014 (without humans).	4.09 (2.23)	2.86 (2.18)	*

F-4 Asteroid and Space Exploration (Pre and Post Survey Comparison)

Table F-4 –A comparison of the mean responses on a scale of 1-7 (Absolutely agree = 1, Absolutely disagree = 7) of participants in both Massachusetts and Arizona combined to the following prompt in the pre-survey (n=189) and post-survey (n=182): "Please assess the following statements about asteroids and space exploration." Responses that are significantly different at $p < 0.01$ (Paired T-test) from the pre-survey to post-survey are marked with an asterisk. Note: Standard deviations are reported in parentheses.

Statements about asteroids and space exploration	*Mean Responses PRE-SURVEY*	*Mean Responses POST-SURVEY*	*Statistical Significance P<0.01*
(1) How we deal with asteroid issues will affect the quality of life for my children.	2.05 (1.16)	2.23 (1.47)	NS
(2) Exploration of asteroids and Mars should be an endeavor the United States does on its own.	4.59 (1.85)	4.93 (2.02)	NS
(3) Exploration of asteroids and Mars should be conducted by an international collaboration.	2.12 (1.29)	1.61 (1.02)	*
(4) If NASA finds valuable minerals, energy sources, and/or sources of water on asteroids, these resources should be publicly owned.	2.65 (1.66)	2.23 (1.54)	*
(5) We will most likely have to exploit resources on Asteroids and Mars due to environmental issues that occur on Earth.	3.21 (1.64)	2.98 (1.80)	NS
(6) We will most likely have to exploit resources on Asteroids and Mars to promote economic growth of financial institutions on Earth.	3.81 (1.76)	3.52 (2.05)	NS
(7) We will most likely have to exploit resources on Asteroids and Mars due political conflict that occurs on Earth (war).	3.96 (1.64)	4.03 (1.95)	NS
(8) I believe that successful deep space exploration (e.g., going to Mars) depends heavily on extensive government funding and oversight.	2.93 (1.50)	2.41 (1.51)	*
(9) I believe that successful deep space exploration (e.g., going to Mars) depends on it being primarily a private enterprise.	4.23 (1.62)	4.24 (1.93)	NS
(10) I believe that successful deep space exploration (e.g., going to Mars) depends on extensive public and private partnerships.	2.34 (1.33)	2.19 (1.49)	NS
(11) Space exploration will stimulate the economy by creating new jobs, new markets, and new technologies.	2.00 (1.20)	1.71 (1.06)	*
(12) Space exploration will make America more economically competitive with other nations.	2.41 (1.31)	2.10 (1.20)	NS
(13) We should explore and do research in space in order to learn more about weather and climate change on Earth, monitor how the Sun affects the Earth, and detect objects that could collide with Earth.	1.72 (0.99)	1.61 (0.98)	NS
(14) We should explore asteroids and Mars to satisfy basic scientific curiosity about the universe.	1.87 (1.17)	1.77 (1.20)	NS
(15) International agreements can have an impact on how the Asteroid Initiative is implemented.	2.11 (1.19)	1.78 (1.11)	*

F-5 - NASA's Planning Priorities — Quantitative Results from Post Survey

Table F-5 – The average responses on a scale of 1-7 (Not a priority = 1, Neutral = 4, Highest priority = 7) of participants in both Massachusetts and Arizona (n=182) to the following prompt in the post survey: "Please assess what you believe should be the most important short-term and long-term priorities of NASA." Note: Standard deviations are reported in parentheses.

Potential NASA Planning Priorities	***Average Responses*** *1 = Not a priority* *4 = Neutral* *7 = Highest Priority*
In the next 10 years, how important is it for humans to travel beyond the International Space Station?	4.82 (1.84)
In the next 50 years, how important is it for humans to travel beyond the International Space Station?	5.42 (1.98)
In the next 10 years, how important is it for a human-crewed mission to orbit Mars or one of Mars' moons?	4.39 (1.82)
In the next 50 years, how important is it for a human-crewed mission to orbit Mars or one of Mars' moons?	5.26 (1.93)
In the next 10 years, how important is it for humans to step foot on Mars?	3.88 (1.95)
In the next 50 years, how important is it for humans to step foot on Mars?	4.96 (2.12)
In the next 10 years, how important is it for humans to establish a permanent presence on Mars?	3.58 (2.06)
In the next 50 years, how important is it for humans to establish a permanent presence on Mars?	4.51 (2.19)

Appendix G – Participant Background Information

"Informing NASA's Asteroid Initiative – A Citizen Forum"

This Appendix contains the background information developed by ECAST in partnership with NASA that was sent to participants in advance of the citizen forum. There are separate sections of the Appendix for each of the thematic sessions that were held at the forum:

- Asteroid Detection: Finding Potentially Hazardous Asteroids
- Mitigation and Preparedness: Responding to the Threat of an Asteroid Impact
- Asteroid Redirect Mission: A Stepping-Stone to Mars
- Journey to Mars: Planning the Future of Space Exploration

Session One
Asteroid Detection: Finding Potentially Hazardous Asteroids

Asteroids may not seem like a big problem compared to all of our everyday concerns, but the potential consequences of a major asteroid collision are devastating. Scientists estimate that asteroids with the power to devastate a city impact Earth about once every 100 years on average. What, if anything, should we do to protect the Earth from this threat?

The threat of an Asteroid Impact

Asteroids have impacted Earth throughout its history. A massive asteroid impact was responsible for the extinction of the dinosaurs 65 million years ago. In 1908, a huge object exploded over a remote location in Siberia, killing thousands of reindeer and killing an estimated 80 million trees over 1000 square miles. Had it struck a more populated location, the effects could have been catastrophic.

The world got a reminder of the potentially devastating consequences of an asteroid collision in February of 2013, when a previously undetected meteor measuring approximately 20 meters in diameter entered Earth's atmosphere and exploded in a large airburst over Chelyabinsk, Russia with the force of many atomic bombs. The shockwave from the explosion led to widespread damage and an estimated 1,500 injuries to residents from secondary impacts such as shattered glass.

16 hours later on the same day, an asteroid about twice the size of the one above Chelyabinsk (estimated diameter: 45 meters) that had been previously detected and tracked by astronomers made the closest approach to Earth that had ever been observed for an asteroid of its size. Although the two events were completely unrelated, this coincidence raised awareness about the potential threat to Earth among the public.

What are our current capabilities for detecting potentially hazardous asteroids?

There is currently no planetary defense agency for the United States, but NASA funds a number of scientific research teams to track Near-Earth Objects (NEOs) such as asteroids and comets. An observer network of asteroid-hunting astronomers works loosely together to find asteroids from the ground, and to share data with one another about the asteroids that they find. Much of the coordination among this group is overseen by the Minor Planet Center at the Smithsonian Center for Astrophysics, which is funded by NASA.

NASA and the Minor Planet Center observe a "6x6" rule, in which if an object comes within 6 Earth radii (about 40,000 kilometers or 25,000 miles) within the next six months, a protocol is activated to share the risk with stakeholders. Astronomers and governments in other countries have their own policies for sharing what they find.

What do we know and communicate about the asteroids that are out there?
Scientists estimate that they have identified well over 95% of the largest "planet-killer" asteroids of over 1 kilometer in diameter, and none of these are likely to threaten earth in the next few centuries. We know far less, though, about smaller asteroids that could cause destruction at regional or urban scales. Congress has charged NASA with the task of finding 90% of all asteroids that are 140 meters in diameter or larger by 2020, but this goal is unlikely to be achieved with current capabilities.

What could be done to improve asteroid detection capabilities?
Right now, we depend on ground-based systems from a global network of observers. But this system has a lot of weaknesses. First, detection is only possible at night, and we don't have coverage in much of the Earth's Southern hemisphere. Also, looking up at space through the Earth's atmosphere makes detection much more difficult than it is from outer space. Weather, moonlight, and distortion from the atmosphere all present challenges to better detection. Finally, looking from Earth makes it very hard to find asteroids that are in orbit similar to our own.

We could augment our existing capabilities from the ground by building new observatories that would increase our coverage area and allow for more standardized detection around the world. This policy might cost about $50 million annually for several decades, and could lead to new breakthroughs in other areas of astronomical research. However, it would still suffer from some of the challenges that come from hunting while down on the ground.

Many experts argue for a space-based detection system. NASA's WISE (Wide-field Infrared Survey Explorer) satellite provides some data about asteroids, but it wasn't really designed for the task and many researchers use it for other purposes. A system of one or two spacecraft could be designed and launched, with a mission of using infrared detection capabilities to identify potentially hazardous asteroids. These space-based telescopes would provide coverage of the whole sky, and being above the Earth's atmosphere allows for more accurate detection. Experts from NASA estimate that this would allow them to find and characterize over 90% potentially hazardous asteroids within a decade. The estimated cost of such an effort would be around $500 million per telescope, which is much more than NASA currently receives for its ground-based detection efforts.

Who Should Guard the Earth?

NASA currently leads most asteroid detection efforts, but there are others who could be part of efforts going forward. With a heightened focus on planetary defense, some people are calling for an international Planetary Defense Agency to be overseen by the United Nations or some other authority. A non-governmental agency called the B612 foundation (named after the asteroid in the story *The Little Prince*) has proposed creating a "Sentinel" satellite within 5 years that would significantly enhance our detection capabilities. Other groups such as the European Space Agency are also working on ways to improve detection. Asteroids also present the potential for space research missions and commercial benefits, and some private industry groups are getting involved.

Your Asteroid Detection Decision at the Forum

During the Forum, you and other participants will consider what the policies for asteroid detection should look like in the future. You will discuss and weigh the tradeoffs, costs, and risks of several potential policy options and recommend what should be done to detect potentially hazardous asteroids. You'll also consider and share your opinion about what groups and institutions should be charged with the task of asteroid detection.

Session Two
Mitigation And Preparedness: Responding to the Threat of an Asteroid Impact

Asteroid detection (meaning finding and identifying asteroids that present a potential threat to Earth) is an important component of planetary defense. Another essential decision point is mitigation. Mitigation refers to what actions (if any) that people might decide to take to prepare and protect the Earth, after an asteroid threat to Earth is identified. There are a number of potential responses that people could decide to take. Each of these possible responses carries a unique mix of tradeoffs, uncertainties, risks, and costs.

Your Mitigation Decision at the Forum

During the Forum, you and other participants will consider two scenarios that describe a threat to Earth from an approaching asteroid. You will discuss and decide what actions you would recommend. There is no one correct answer in any of these cases, because the decision to take (or not take) any particular action depends on individual perspectives and values that will not be the same for everyone. For each scenario, you and your fellow participants will consider and recommend what mitigation option(s) (if any) to enact and who should implement them.

To help inform the best possible decisions, it is important to understand the mitigation options that are available to decision-makers, and how each of these options might be applied.

Risk factors for Asteroid Impact

Impacts from near-Earth object (NEO's) have occurred throughout Earth's history, and we know that these impacts are inevitably going to continue. Potential negative consequences of an asteroid collision range from harmless fireballs in the atmosphere (which occur very often with asteroids that are only a few meters across in diameter) to airbursts or dust clouds all the way to catastrophic events with the potential for massive loss of life. The decision of whether and how people should respond a detected asteroid threat will depend upon a number of factors. These include: the severity of the collision's impacts upon Earth, where and how it is predicted to impact, and the cost, uncertainty, and time associated with all of the potential mitigation responses.

The process for assessing and characterizing potential impacts from an asteroid collision is complex and involves many factors. But the three most important factors affecting the potential danger to people on Earth, and the ones that we will focus on to inform your discussions are:

- The mass of the asteroid. In general, the more massive the asteroid, the greater the potential threat. The mass of the asteroid depends largely on the size of the asteroid and what materials it is made of.
- The speed of the object as it approaches Earth.
- The estimated distance and time to Earth impact after the asteroid threat is identified. Detection time can range from hours or days to decades or centuries.

Potential actions for mitigation
Many ideas have been proposed for preparing and protecting the Earth from the threat of an imminent asteroid collision. These mitigation options vary tremendously from one another in terms of how much each would cost, how much warning time each would require, what the risks and potential unanticipated consequences are, and how close each of techniques is to being ready to deploy if needed. Some could be deployed rapidly if an asteroid were detected tomorrow, while others would require huge programs to establish their readiness.

For the Asteroid Forum, you and your fellow participants will consider four potential options for mitigation: civil defense, nuclear explosives, kinetic impactors, and gravity tractors. We explain the concept and tradeoffs around each of these proposed strategies below. These strategies could be adopted by themselves, or in some cases could be combined together to respond to a threat of an asteroid collision. Your group will have the option of recommending all, some, or none of the actions for each of the scenarios you will consider at the Asteroid Forum.

Civil Defense: Communication and Preparation. Civil defense does not actually reduce the probability of asteroid collision, but rather involves notifying citizens and decision-makers, and preparing people and infrastructure on Earth for the asteroid's impact. It is likely that civil defense would be adopted to some degree in response to any imaginable asteroid threat, but the scale and timeframe for communication and preparation would depend on the specific situation. Civil defense actions may involve communicating risks, so residents and decision-makers can plan and prepare for the impact. Disaster preparedness actions may include preparing buildings or infrastructure for increased resilience, planning and preparing for the evacuation and/or sheltering of at-risk populations, stockpiling food and energy resources, and could also lead to agreements between global or national governments to help groups of people adapt. Civil defense strategies can be implemented on the scale of weeks or years, depending on what policies have been put into place before the asteroid is detected.

Important considerations include: the costs and logistics required for preparation, the dynamics of international or regional agreements to prepare for collision, the risks of causing an unnecessary panic if the asteroid does not actually impact the planet, and the tradeoffs between preparing the Earth and taking other kinds of actions to actually prevent the asteroid from reaching the Earth.

Kinetic Impactors: Ramming an asteroid. Kinetic impaction involves sending one or more large, high-speed spacecraft into the path of an approaching near-earth object. This could deflect the asteroid into a different trajectory, steering it away from the Earth's orbital path. NASA demonstrated on a small scale with the Deep Impact mission of 2005. If preparations were made in advance so that kinetic impactors were available upon detection, the National Academy of Sciences would require a warning time of at least 1 to 2 years for smaller asteroids. If an approaching asteroid were detected tomorrow, perhaps 20 years would be required to build and launch an impactor, to reach and impact the target, and to nudge the asteroid from Earth's path. However, decades or more might be required to deflect larger asteroids (hundreds of kilometers in diameter) that present the most catastrophic threats. If time allows, a mission to study the asteroid up close and send information back to Earth before sending the impactor could greatly increase the chance of success. Kinetic impactors may not be effective in changing the orbit of the very largest asteroids.

Important considerations for kinetic impactors include: the potential for mission failure, the need for prolonged detection times, the risk of breaking the asteroid into smaller pieces that could still threaten Earth, the cost and factors needed to accomplish the mission, and the tradeoffs with other potential mitigation and/or civil defense actions.

Blast deflection: Earth has an arsenal of many nuclear or other kinds of explosives, held by nations around the world. Some experts have proposed launching nuclear explosives from the Earth to disrupt, destroy, or redirect an approaching near-earth object. This may be the only strategy that would be effective for the largest and most dangerous "planet-killer" asteroids (over 1 kilometer in diameter). Blast deflection could also be used if one of the other approaches are attempted and are unsuccessful. A NASA study from 2007 concluded that nuclear standoff explosions were likely to be the most effective method for diverting an approaching near-Earth object. However, nuclear explosives are a controversial technology, are technically banned from use in outer space, and are the subject of many geopolitical disputes. Blast deflection could result in fracturing the asteroid into smaller pieces that could still threaten the Earth. However, it may be more appropriate for dealing with an approaching rubble pile than kinetic impactors would be. Important considerations for blast deflection include the potential for mission failure, the need for international cooperation, and the readiness of the techniques.

Gravity Tractors: If an approaching asteroid were detected early enough, it could be possible to divert its path using the gravity of a spacecraft. Instead of sending an impactor to ram into an approaching object, a gravity tractor device would fly alongside the asteroid for a long period of time (years to decades) and slowly pull it out of Earth's path. Gravity tractors would be most likely to work on any shape or composition of approaching asteroid, even if it were just a pile of rubble. However, gravity tractors might not be effective for the largest asteroids of over 500 meters in diameter which might be the greatest threat to Earth. Gravity tractors offer the greatest control and could perhaps even divert an approaching asteroid to other locations in space where people could theoretically use them for research or commercial purposes. However, these techniques have never been tried and would require decades for building, launching, and carrying out a mitigation mission.

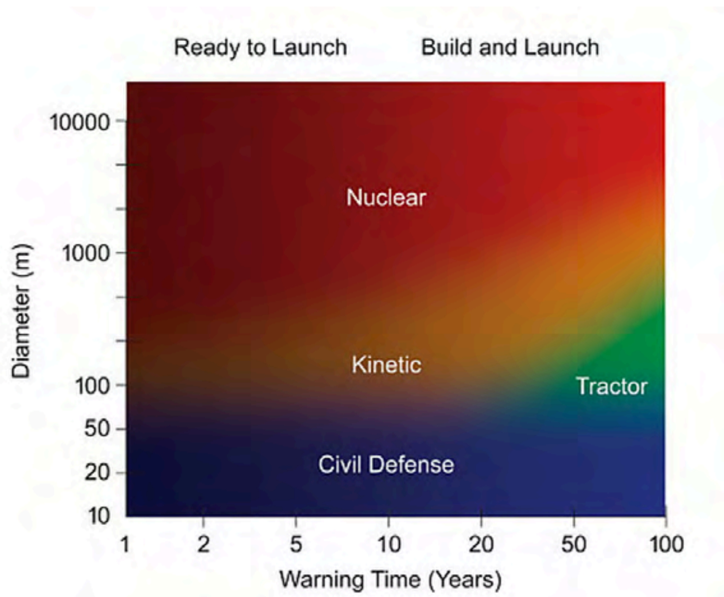

Figure 5.5 from *Defending Planet Earth: Near-Earth-Object Surveys and Hazard Mitigation Strategies,* National Academies of Science report (2010)

Session Three
Asteroid Redirect Mission: A Stepping Stone to Mars

In what is being called the 'Proving Ground', NASA is taking aim at the future of deep space exploration by demonstrating technologies necessary for extending our reach in the Solar System. The Asteroid Redirect Mission is a key milestone on this path. By relocating an asteroid to orbit the Moon and then sending crewed missions to that asteroid, many of the techniques and capabilities that are needed for eventually exploring Mars and beyond will be proven in a space environment.

What is a Capability-Driven Framework?

One of the development strategies for the advancement of human exploration of the Solar System is to follow a capability-driven framework. NASA's capability-driven framework is a departure from the traditional space mission model. Instead of selecting a destination – like the moon or the International Space Station – and building the transportation vehicles to get there, this approach develops the vehicles and capabilities that can go to a broad range of destinations. As these vehicles and capabilities mature, increasingly complex missions can be selected to destinations farther and farther into the solar system.

This means that missions are funded, designed, and carried out as NASA's budget and capabilities dictate. Rather than a detailed start-to-end plan, such as the Apollo Program had for lunar exploration in the 1960s, this approach does not need final, fixed goals in place before initial missions are carried out.

This method has the potential to be more efficient and cost-effective, as the path towards the eventual goal of Mars exploration is flexible. Technologies can be developed, tested, refined, and perfected in a lower-risk environment than a crewed Mars mission.

What is the Proving Ground?

Merriam-Webster defines "proving ground" as a place where things or people are tested or tried out for the first time; a place where scientific testing is done. NASA refers to the Proving Ground as a phase of human and robotic missions that prepare for and prove our ability to safely live and work away from Earth for extended periods of time. The proving ground is centralized in cis-lunar space, but encompasses activities conducted aboard the International Space Station, and robotic missions on and around the moon, Mars, and farther into the cosmos.

NASA's capabilities will continue to mature through missions in the Proving Ground, leading to the ability to go to Mars. As such, the Proving Ground and the Capability-driven Framework are related, as the final destination and mission concept for human exploration is not defined for the Proving Ground. The Proving Ground can be viewed as a method of moving NASA from earth-dependent to earth-independent in smaller increments and in full before attempting a mission to Mars.

What is the Asteroid Redirect Mission?

The Asteroid Redirect Mission or ARM will be the first major Proving Ground Mission. There have been other proposed Proving Ground missions to destinations in cis-lunar space and Mars. ARM will capture a small near-Earth asteroid and place it into orbit around the Moon. Once the object is in lunar orbit, a crewed mission will be sent to rendezvous with the asteroid and obtain samples for Earth-based analysis. Many new technologies and techniques will be demonstrated, including propulsion systems and crew habitats. In addition, other mission components will advance parallel fields such as planetary defense capabilities. ARM is just one of a series of Proving Ground missions that will 'pave the road' for the future, including the eventual exploration of Mars. There are two robotic mission options being considered.

What are the two potential robotic mission scenarios, and how do they differ?

Option A involves the capture of a single asteroid approximately 10 meters in diameter. A large, inflatable bag will be deployed around the object, and the entire asteroid will be redirected to lunar orbit. This will result in a much larger object being available for study, increasing the volume of samples available to astronauts and also eventually yielding more material.

There is a possibility that this technique will be relevant to clearing space junk and other debris from low Earth orbit or orbits around other bodies. Due to the uncertainties in characterizing such a small object, the asteroid might be a loosely held together 'rubble pile' rather than a solid object.

Option B instead aims to retrieve a 2-3 meter boulder from the surface of a much larger asteroid. The "much larger object" referred to in Option B is relative to the size of the asteroid/object that would be targeted in Option A. Option A targets a ~10m, free-flying monolithic asteroid. Option B targets an asteroid that is hundreds of meters in size, covered with boulders that could be retrieved from its surface.

Using a type of grabbing device, the spacecraft would land on the asteroid's surface, attach itself to the target boulder, and then lift off in order to place the boulder in lunar orbit. Ground-based observations will be more able to identify the composition of this larger asteroid, and the added mass of the boulder will have more of an impact in the planetary defense demonstration element of the robotic mission.

The additional maneuvering required by Option B could also be more relevant in informing engineers about similar future missions, such as landing on the moons of Mars. The mission would have a multitude of target boulders to choose from, but removing any boulder could prove challenging.

How does the Asteroid Redirect Mission advance planetary defense technologies?
During the capture phase of the mission, a gravity tractor demonstration will be performed on the target asteroid. The gravity tractor method leverages the mass of the spacecraft to impart a gravitational force on the asteroid, slowly altering the asteroid's trajectory. In both Options A and B, the robotic spacecraft will initiate an orbit around the asteroid to transmit the required impulse to the asteroid. For Option A, the robotic spacecraft will be empty, conducting the demonstration on the target asteroid before enveloping it. For Option B, the robotic spacecraft will conduct the demo on the large asteroid, with the small boulder in its clutches. The boulder's additional mass enhances the gravitational force that the spacecraft can transmit to the asteroid.

Before making the capture, the orbital path of the asteroid around the Sun will be altered. This demonstration will be the first attempt to change the trajectory of a near-Earth object. While the final selected target will not be considered hazardous in terms of size or location, testing this mitigation technology will help us better prepare for deflecting future hazardous objects.

Your Asteroid Redirect Decision at the Forum
During the Forum, you and other participants will discuss the merits and advantages of the two finalist mission scenarios with regards to relevance to planetary defense, benefits in terms of scientific and material gains, and usefulness in terms of furthering human exploration. You will consider both of the options and ultimately choose one that you feel would provide the most benefit to NASA's future plans. There is no one correct answer in any of these cases, because the decision to take (or not take) any particular action depends on individual perspectives and values that will not be the same for everyone. Below is a summary of the two options.

Option A - Pro	*Option A - Con*
Larger object being available for study: Option A is targeting a ~10m asteroid, while Option B is targeting a 2-3m boulder. Therefore, the returned asteroidal mass in Option A will result in a larger object being available for study **Relevant to clearing space junk**: When the capture mechanism is deployed, it is essentially a large, inflatable bag with a strong yet flexible frame. As envisioned with the ARM mission, it is capable of enveloping free-flying objects. At increased scales, the concept could be extended to clear "space junk" from Earth's orbit. Space junk could include spent rocket stages, old satellites, or other fragments that could collide with operational spacecraft.	**The asteroid might be a loosely held together 'rubble pile' rather than a solid object**: Objects that are within the size range of Option A (~10 m) are difficult to characterize from Earth. What may seem like a monolith may actually be a clump of rubble, held together by gravitational forces. Approaching the rubble could disrupt the debris, resulting in a smaller sample collected than anticipated. Additionally, for the crewed segment of the mission, approaching the debris for investigation and sampling could prove more challenging due to debris mitigation protocols for astronauts.

Option B - Pro	*Option B - Con*
Ground-based observations will be more able to identify the composition of this larger asteroid: As stated above, the larger asteroids are easier to characterize, so the advanced knowledge of the target's composition, rotation, shape, precise orbit, and spectral class will help to inform mission planning. **The added mass of the boulder will have more of an impact in the planetary defense demonstration element of the robotic mission:** Please see answer to question above about "greater mass" **The additional maneuvering required by Option B could also be more relevant in informing engineers about similar future missions, such as landing on the moons of Mars**: The robotic spacecraft would have to rendezvous with the large asteroid, adjusting its propulsion and trajectory to the asteroid's, possibly performing real-time investigation of boulder options before selecting the best one to retrieve. It will descent to the surface in a low-gravity environment while the asteroid is on its rotational axis. The surface landing will have to be precise, positioning the robotic arms sufficiently around the boulder in order to be able to lift it from the surface. This advanced maneuvering will be greatly informative for future missions, particularly those to Mars' moons, Phobos or Deimos, because they share similar traits with large asteroids – in fact many people believe they are asteroids that were caught in Mars's gravitational pull.	**The mission would have multiple target boulders to choose from, but removing any boulder could prove challenging:** The boulders on a large asteroid could be loosely adjacent to the surface of the asteroid, or may have over the years bonded to the asteroid surface. Plucking the boulder from the surface could be as easy as land-grab-go, but it could also require agitation or drilling to free it from the surface.

More information about the options for the Asteroid Redirect Mission is available at these links:
Option A:
http://www.lpi.usra.edu/sbag/meetings/jul2014/presentations/1030_Wed_Muirhead_ARM_OptionA.pdf
Option B:
http://www.lpi.usra.edu/sbag/meetings/jul2014/presentations/1030_Wed_Mazanek_ARM_OptionB.pdf

Session Four
Journey to Mars: Planning the Future of Human Space Exploration

The complexities and challenges that need to be faced when planning a crewed mission to the planet Mars are vast. The incredible distances and harsh conditions render such an endeavor many times more difficult than any previous space initiative. While developing a plan for what a Mars mission would look like is important, it is also of critical importance to look towards the more immediate future and decide what agencies like NASA can be doing in preparation for the most ambitious exploration agenda in human history. What are the problems that engineers and astronauts must solve when planning for Mars, and what framework will result in the most rapid, cost-effective, and successful navigating of those challenges?

What considerations need to be addressed when planning a mission to Mars?

- **Timeframes** While the Earth and Moon vary in distance very little over time, the position of Mars relative to Earth can change quite drastically on the timescale of months. This limits the windows of opportunity for launching spacecraft and also constrains the time it takes to reach Mars. A typical travel time for the spacecraft that have been launched to Mars is 5 months; compare this to 3 days for astronauts to reach the Moon. Advanced propulsion technologies could cut this down significantly.

- **Radiation** Mars lacks a magnetic field. On the Earth, this shields us from much of the Sun's harmful radiation. While traveling to Mars for many months and once at the red planet, astronauts can expect to receive a significant amount of radiation. Spacecraft and habitats that are capable of protecting the astronauts will need to be developed, but even with such technology, the risk of negative health effects remains significant.

- **Surface conditions** The atmosphere of Mars is two hundred times thinner than that of the Earth and composed primarily of carbon dioxide. The surface temperatures can drop as far as -200^0 Fahrenheit. Advanced habitats and space suits would need to be designed in order to maintain survivable conditions on the surface of Mars for many months at a time.

- **Supplies and fuel** Due to the distances involved, resupplying a Mars mission from Earth is impractical unless planned out months in advance. If critical habitat components fail, relying on backup parts to arrive from Earth may not be possible. With the advance of technologies such as 3D printing and in-situ resource utilization, astronauts may be able to manufacture their own fuel, air, water, and other supplies from resources found on Mars.

- **Phobos and Deimos** Mars has two small moons which are thought to be captures asteroids. While the Earth's moon is over 3,000 kilometers in diameter, neither Phobos nor Deimos is larger than 27 kilometers in any dimension. Even though the distance required to travel to these moons is the same as traveling to Mars, their much lower mass results in a far easier landing/takeoff procedure. For this reason, a crewed mission to Phobos or Deimos would necessitate a lower level of capability than a crewed mission to the surface of Mars.

Options for a Crewed Mars Initiative

- **Robotic and Orbital/Moon Missions** This scenario involves a much larger array of robotic explorers being sent to Mars than NASA currently has. In addition, crewed missions would be sent to orbit Mars and possibly to Phobos and Deimos. While this option does not involve a crewed landing on the surface of Mars, the astronauts in orbit would be able to remotely operate robots on the surface in a much more efficient and directed manner than teams on Earth.

Since this is the least intensive option in terms of scale, it is also the least expensive and involves the smallest amount of risk. Without the need for human-rated landing and takeoff vehicles, the amount of research and engineering that would need to be undertaken is a fraction of a mission involving a crewed landing, lowering cost and making this scenario possible on a fairly short timescale.

The absence of setting humans on Mars also results in a substantial reduction in the risk to the astronauts in many respects. The amount of science that can be done pales in comparison to any mission with a crewed landing on the surface of Mars. This option also may be less exciting to the public than full human exploration missions.

- **Viking Strategy** This scenario involves a small-scale crewed exploration mission that would set down on the surface of Mars and operate for several months before the crew would return to Earth. Eight astronauts would be selected to make the journey, and it would be launched at a time that would provide for not only a short travel time but also the shortest possible stay on the surface to minimize risk to the astronauts.

Having astronauts on the surface of Mars would greatly increase the relevance and amount of science data that the mission would yield compared to remote operation of robots. However, the technical and engineering hurdles that need to be addressed result in a major cost and timeframe increase. While risk would be minimized, it would still be substantial for all of the astronauts involved.

Without a permanent habitation plan, there is the risk that the mission will suffer a fate similar to the Apollo Program. That is, once we accomplish a crewed landing on Mars, interest and support in the Mars program may wane to the point of cancelling any future missions.

- **Pioneer Strategy** This scenario involves a permanent settlement on the surface of Mars. This colony would be preceded by a fleet of robotic and supply ships that would deposit food, fuel, and materials on the surface. These robots would also begin preparations for constructing permanent habitats. An initial large crew of human explorers would be refreshed every few months both in terms of supplies and personnel.

A mission of this scale and duration would be able to unlock a large number of the mysteries we have concerning the history of Mars and the entire Solar System. Multiple locations could be settled or scouted, offering opportunities for an abundance of diverse scientific research. Humanity would become 'Earth-Independent', meaning that such a mission might no longer require support from our home planet and may become self-sustaining.

The technology and techniques required for such an undertaking would be extremely challenging. Methods of dealing with radiation, extracting water, producing fuel and air, propulsion, habitat construction, and a number of other techniques would need to be vastly improved before this scenario becomes feasible. It would involve a colossal increase over a smaller-scaled surface exploration mission in terms of cost, risk, and timeframe.

The Asteroid Redirect Mission and the Proving Ground

With the challenges for a crewed Mars mission defined and potential exploration scenarios outlined, it is obvious that the engineers and scientists of today need a framework that will allow for a successful Mars campaign. While some advocate laying an entire plan down from test missions through final exploration plans from the very beginning, there are other options for organizing the efforts that must be made. One of these options is the Proving Ground concept, which allows for missions to be designed, funded and carried out as NASA's budget and capabilities dictate.

An example of the Proving Ground approach to Mars exploration was seen in the last discussion - NASA's upcoming Asteroid Redirect Mission. While there is merit in the mission itself, it really serves primarily as a stepping stone towards the overarching goal of crewed Mars exploration. Many missions such as this would allow for the capabilities necessary for Mars exploration to be designed, tested, improved, and perfected on an increasing level of complexity and distance from the Earth. Smoothly transitioning from our current capabilities to the set of technologies and techniques necessary for a large-scale Mars initiative will likely be more cost-effective than planning an entire Mars mission start to end.

Your Path to Mars Decision at the Forum

During the Forum, you and other participants will discuss the different options for an eventual Mars exploration mission with a focus on the Proving Ground strategy. You will consider the options for a crewed Mars initiative in terms of scale, science benefits, cost, and even whether each option would be exciting or worthwhile. However, the main part of the discussion will focus on the more immediate future, and how the plan for Mars should be laid out as we move forward – would you like to see an entire strategy laid out now, or are you comfortable with a series of Proving Ground missions (such as the Asteroid Redirect Mission) that are undertaken as budgets and capabilities dictate?

Appendix H – Table Observation Protocol and Overview of Statistical Analyses

Informing NASA's Asteroid Initiative
Table observation protocol

For use with both the Phoenix and Boston in-person deliberations

The purpose of the table observations is to provide data that can help answer two questions:

- What was the quality of the deliberation?
- What reasoning did the participants use in developing and expressing their views on the questions put to them in the course of the day?

Specific instructions follow.

What you should say and do

- Record all of each session. Bring a recorder if you have one, otherwise contact Rick Worthington at rworthington@pomona.edu to make arrangements. If you bring your own recorder, test it ahead of time and make sure you have backup batteries.
- The recording is for your use when you write up your notes of the day's activities, and does not need to be transcribed.
- Introduce yourself briefly at the beginning of the day, explain that you will be observing the conversation in order to better understand how people develop the ideas that are provided in response to questions throughout the day. No one's name is being recorded (first name only) and participants will remain anonymous in any report that uses these observations.
- Explain that you will only observe and will not participate in the conversation at the table, but that you might talk informally with people during breaks if they are comfortable doing that.
- Feel free to informally talk with a participant from your table regarding the substance or process of the deliberation at lunch, during a break, or after the deliberation in order to better understand his or her thinking and opinions.

Things to look for in the conversation at your table

Quality of deliberation:

- How clear or unclear was the information material (print and video) to the participants, and how well/how much did they use it in their conversations?
- What was the quality of the conversation? For example, to what extent did people take turns, listen attentively, participate equally, and engage different views directly, respectfully and in a manner that produced improved understanding?
- How did participants frame the issue, e.g., how much were their views based on the merits of the Asteroid Initiative goals vs. the perceptions of NASA and others who are in charge of it?

Reasoning:

- How much did participants rely on the information material and the conversation to develop and express their views, vs opinions that they have independent of the deliberation?
- What substantive reasoning did people (or groups) provide for their views?

Other things to observe

- Do the spatial aspects of the room (seating, objects, technologies, sound, distractions) impact or facilitate deliberation, and if so, to what degree?
- Were the designated topics for deliberation or procedural rules ever questioned during the deliberation?
- Did you observe any interesting interactions or conversations among people at the deliberation (e.g., between a facilitator and participant during a break, or between two participants, etc.)?

Writing up the results

Please review and supplement your notes to clarify or fill gaps within 24 hours while the material is fresh, and write them up within a week.

- Post your report to Dropbox folder 'NASA pTA 2014 > Assessment > Table observer reports.'
- Use the following filename protocol: [yourlastname.city.report]. Be sure to put your name and email on the notes so that any other table observers can contact you if they have any questions.
- Clearly label each session or other context for your observations.
- At the beginning of your notes for each session identify the people at the table, e.g., Bob, Lucas, Maria, Massoud, etc. If there are two people with the same name, ID them as Lucas1, Lucas2. This will help you to keep track of who is speaking when you take notes, and you can use the names as appropriate when writing up your report by, e.g., quoting or paraphrasing something that Massoud said.
- Your notes do not need to be an exhaustive account of the conversations during each session. Instead, you should report on the table discussions in chronological order, identifying the progression of the main topics addressed within each session to the extent possible. Things often go back and forth or into an indeterminate space, and it is not necessary to document all these moves. The purpose is instead to provide a general sense of the flow of topics discussed and your observations of the noteworthy things that transpired within each of these 'segments' of the session.
- Observe, don't analyze.
- Label and report observations about things outside the table deliberations chronologically, i.e., if you talked with a participant during lunch, this should be included in your report after the morning sessions and before the afternoon sessions.
- Based on these observations, add any overall observations or insights at the end of your notes.

Thank you!

Overview of Statistical Analysis

Below is a brief explanation of the statistical analyses used throughout this report. For all statistical analyses, we considered a statistically significant difference at a p-value of 0.05 or lower.

Chi-square Goodness-of-Fit Test – We used this analysis to test for significant differences among all individual frequency counts of voting results. For comparisons between only two categories, Fisher's Exact Test was used in order to avoid the potential for a false positive due to low sample sizes and a degree of freedom less than 1.

Two-sample T-test – We used this analysis to test for significant differences between the means of two independent samples. For example, we used this test to determine if there were mean differences on survey data between Arizona and Massachusetts.

Paired T-test – This analysis is used to test for mean differences between paired dependent observations. In this report, we used paired t-tests to compare mean differences between repeated questions on both the pre-survey and the post-survey. In these surveys we repeated questions to measure whether learning occurred during the event and whether participant attitudes toward various aspects of the Asteroid Initiative and NASA changed during the event.

One-way Analysis of Variance – We used this analysis to compare the means of more than two categories at one time. For example, when there was a block of related survey data (e.g., motivations for attending the Informing NASA's Asteroid Initiative Forum) with several categories, we used a one-way analysis of variance to test for overall differences among the means of all the categories. At the same time, a Pairwise Tukey Analysis was performed to test for potential mean differences between all possible category pairs. This analysis also helps identify clusters of similar mean responses on the survey data (see Tables 2.7 and 5.2).