Public Meeting of the

President's Council of Advisors on Science and Technology (PCAST)

September 12, 2024

Meeting Minutes

MEETING PARTICIPANTS

PCAST MEMBERS

1. Frances Arnold, Co-Chair
2. Arati Prabhakar, Co-Chair
3. Maria T. Zuber, Co-Chair
4. Dan E. Arvizu
5. Dennis Assanis
6. John Banovetz
7. Frances Colón
8. Lisa A. Cooper
9. John O. Dabiri
10. William Dally
11. Sue Desmond-Hellmann
12. Inez Fung
13. Andrea Goldsmith
14. Laura H. Greene
15. Paula Hammond
16. Eric Horvitz
17. Joe Kiani
18. Jon Levin
19. Steve Pacala
20. Saul Perlmutter
21. William Press
22. Jennifer Richeson
23. Vicki Sato
24. Lisa Su
25. Kathryn Sullivan
26. Terence Tao
27. Phil Venables
28. Catherine Woteki

PCAST STAFF

1. Lara Campbell, Executive Director
2. Melissa A. Edwards, Deputy Executive Director
3. Bich-Thuy (Twee) Sim, Assistant Director for Transformative Medicine and Health Innovation
4. Sachin Shah, Policy Analyst
5. Kelli Moore, Policy Analyst

INVITED SPEAKERS (IN ORDER OF PRESENTATION)

1. Kara Kockelman, Dewitt Greer Centennial Professor in Transportation, The University of Texas at Austin

2. Ben Levine, Deputy Assistant Secretary for Research and Technology, Department of Transportation
3. Steve Armato, Vice President for Amazon Transportation Services Product and Technology, Amazon
4. Rachael Nealer, Deputy Director, Joint Office of Energy and Transportation
5. Zachary Kolodin, Chief Infrastructure Officer and Director, Michigan Infrastructure Office
6. Nathaniel Ford, Chief Executive Officer, Jacksonville Transportation Authority (JTA)
7. Edwin Olson, Chief Executive Officer, May Mobility
8. Paul E. Krajewski, Director, Connected Vehicle Experience Research, General Motors Global Research and Development Center
9. Luke Polcyn, Senior Executive for Development and Economic Transformation, City of Detroit Mayor's Office

START DATE AND TIME: THURSDAY, SEPTEMBER 12, 2024, 9:20 A.M. Eastern Time

LOCATION: Michigan Central, Detroit, MI, and Virtual via Zoom.gov

WELCOME

PCAST Co-chairs: Frances Arnold, Arati Prabhakar, Maria Zuber

The PCAST co-chairs called the meeting to order – Frances Arnold, California Institute of Technology; Arati Prabhakar, Science Advisor to the President; and Maria Zuber, Massachusetts Institute of Technology. Arnold stated that the day's three open sessions would focus on the future of transportation, infrastructure planning and implementation, and transportation innovation.

SESSION: THE FUTURE OF TRANSPORTATION AND TRANSPORTATION INFRASTRUCTURE, PLANNING, AND IMPLEMENTATION

KARA KOCKELMAN

Kockelman said transportation costs Americans an average of over $9,000 annually, spending approximately $4,000 each year to own and park a vehicle. Crashes add another $3,000 a year; fuel expenses average $800 a year, including just $100 a year in gas taxes; and carbon and other emissions, including particulate matter precursors, account for approximately $1,200 a year. In addition, transportation incurs additional costs in terms of noise, visual blight, habitat and species loss, fear of walking and biking, health care costs from sedentary lifestyles, and other indirect expenses. She noted she and her students have built shared, autonomous, all-electric vehicle networks providing first- and last-mile services to deliver people to mass transit stations in Austin, TX; 20 counties across the Chicago region, and 10 counties across the Dallas-Ft. Worth region. Her team is conducting simulations to determine the optimal size for self-driving vehicles used in this manner.

New technologies, said Kockelman, come with benefits and drawbacks. For example. Battery-powered electric vehicles plus a smarter grid operating on cleaner feedstocks can lower damages from roadway emissions by approximately 90 percent, or $1,000 per person per year. Autonomous vehicles (AVs) can reduce crash costs by 85 percent, or $2,500 per person per year, and cut perceived time costs by 25 percent per person per year. However, because full automation makes driving easier than it already is in the United States, congestion and gridlock would increase, as might emissions. The results of her team's work suggest that addressing these potential problems would require distance-based and credit-based congestion tolls, empty driving limitations, and subsidizing right-sized, shared electric vehicles similar to a minibus that turn off when not in use.

Kockelman recommended instituting electric bicycle and shared electric vehicle ride subsides instead of the $2 per person-mile on poorly used conventional transit systems, which is 10 times the cost of filling a private car. Up-zoning to allow for two or more housing units on a single-family lot could reduce transportation costs, something California and Minneapolis, MN, have instituted. Another option would be to institute full-cost pricing of roadways at 5 cents per mile, emissions pricing at 1 to 10 cents per mile, and parking at 10 cents to $1 per mile. Peer countries, she said, already require automatic breaking for pedestrians; speed limiters and 25 cent RFID tags for automated speed enforcement in dangerous settings, and on-board dongles for GPS-based tolls. They also vary vehicle registration fees and sales taxes by size and emissions levels and provide mobility wallets. The United States, she said, is lagging on deploying these solutions.

Ben Levine

Levine noted that federal research and development (R&D) spending on transportation is low compared to other regulatory sectors, with significantly more R&D spending on aircraft and vehicles than on infrastructure. The Department of Transportation (DoT) has an annual R&D budget of approximately $1 billion, about half of which goes to the Federal Aviation Administration (FAA) and 20 percent goes to the Federal Highway Administration (FHWA). Relative to their contribution to the nation's gross domestic product, federal and state funding is 10 times higher in health and energy than in transportation. In addition, the private sector invests more than $50 billion on automotive and aircraft manufacturing R&D. The takeaway, said Levine, is that DoT is not considered an R&D agency, but it is doing the best it can with the resources it has.

As examples of the research DoT funds, Levine cited FAA-funded research on sustainable aviation fuel testing and analysis totaling $18 million and FHWA's Complete Streets Initiative at $2 million. The latter looks at the impacts and effectiveness of different efforts to blend serving pedestrians, bicyclists, public transportation users, motorists, freight vehicles, and others safely and efficiently. The National Highway Traffic Safety Administration is spending $11 million developing two technologies for a driver alcohol-detection system, and DoT's university transportation centers program spends almost $100 million at 35 centers on a variety of projects, including simulations for cyberthreats within the transportation sector.

Levine discussed the envisioned Artificial Intelligence (AI) for Transportation Safety Projects program for mapping, visualizing, and building the future. This project is aspirational, though it is funding pieces of this across its R&D portfolio that aim to increase the safety of moving around in public. He noted that over the past three years, roadway fatalities have claimed over 40,000 lives in the United States. The idea here is to create a digital representation of the nation's physical infrastructure to unlock an ecosystem of

innovation that would engage academia, the private sector, and startups in R&D to develop scalable applications and approaches that state and local agencies could deploy to make the nation's roads and highways safer for everyone. A more sophisticated and detailed digital representation of a city's intersections, for example, might identify places where crashes or potentially dangerous bicycle-car or pedestrian-car interactions were more likely to occur before they happen. DoT's proposed National Transportation Infrastructure Observatory would oversee such a project.

Steve Armato

Armato explained that Amazon built its logistics network over the past 22 years, gradually expanding from an initial five central fulfillment centers and adding shipping and storage capacity. Today, many of these sites leverage robotics and other collaborative technologies that have created a safer and more ergonomic workplace. Amazon has collaborated with other carrier partners to consolidate its package volume and build out its sorting and trucking network. At each step in this expansion, Amazon has leveraged technology to scale and optimize operations and increase agility in the face of disruptions and to further improve cost, speed, and sustainability.

Armato said disruptions have become increasingly common in the globalized supply chain, and Amazon wants to have its network adapt automatically, preferring dynamic, real-time decisions over static decisions and leveraging algorithms and optimizations to make those decisions. For example, Amazon's global logistics network has increased the number of ports of entry it uses so it can reroute imports as needed if there is a disruption. He noted that Amazon is now taking a regional approach and reworked its network infrastructure so that customer orders are filled primarily by the closest fulfillment center. Accomplishing this required being able to predictably place inventory near the customer.

Amazon is excited about robotics, said Armato, and is now the world's largest manufacturer of industrial robotics. The company has deployed over 750,000 robots and continues to invest in robotics and collaborative technologies. In addition to improving safety, he added, robotics and other technologies have created new job opportunities, with Amazon creating 700 new job categories.

Looking to the future, Armato said in addition to robotics, Amazon is excited about AI and machine learning. Already, generative AI is part of the company's DNA, having been working with these technologies for over 20 years. Its initial efforts were in personalization and forecasting, and the company sees generative AI as the powering the next generation of innovation, just as networking, personal computers, and the internet were. Today, Amazon is applying generative AI to avoid congestion and manage traffic patterns within its robotics fleet, and it has ongoing efforts in prescriptive analytics and package auditing at scale. The latter aims to use data on the billions of packages it ships along with computer vision and generative AI to audit packages before they are sealed and shipped.

Armato said Amazon is excited about using the Internet of Things's ability to generate data and track shipments and its vehicles. The goal is to optimize transportation. He noted that the company is investing $750 million in 2024 on safety-related technologies, such as in-vehicle cameras and telematics in its fleet. Together, these have dramatically improved the company's traffic safety record.

Armato explained that as the company adopts new technologies, it is emphasizing upskilling among its workforce. It's Career Choice program offers 750,000 employees globally the opportunity to engage in on-

the-job learning and upskilling. Its AI Ready program promises to provide up to two million people in the general public with free AI skills, and it has started a $12 million scholarship fund for individuals from underrepresented communities to learn generative AI. The company also has stated its goal of reaching net-zero carbon emissions by 2040.

ARNOLD MODERATED THE Q&A AND DISCUSSION BETWEEN PCAST MEMBERS AND KOCKELMAN, LEVINE, AND ARMATO.

SESSION: TRANSPORTATION INFRASTRUCTURE, PLANNING, AND IMPLEMENTATION

Zuber, when introducing this session, noted that transportation infrastructure serves as the backbone for economic activity, social mobility, and local and regional connectivity. Optimizing infrastructure requires considering sustainability, resilience, accessibility, and equity, and it should infuse judicious use of new technology.

RACHAEL NEALER

Nealer addressed how the Joint Office of Energy and Transportation is supporting the transition to a fully decarbonized and electrified transportation sector that the federal government outlined in its 2022 decarbonization blueprint. Electrification is the biggest change to the U.S. transportation system in a century, and while numerous strategies and solutions are required to tackle transportation emissions completely, electrification holds the greatest promise to produce the biggest reductions. One advantage of electrification is that it is ready to deploy now. Along with electrifying vehicles comes a once-in-a-lifetime investment goal and vision in the Biden-Harris Administration's budget on electric vehicle (EV) infrastructure. Congress has supported the goal of installing 500,000 chargers by 2030 with $7.5 billion in public investments in a fast-charger network and community charging.

Today, said Nealer, the first stations funded by this investment, many resembling gas stations, are operating in Ohio, New York, Pennsylvania, Hawai'i, Maine, Vermont, Utah, and Rhode Island. Hundreds more charging stations will be operating by the end of 2024, with thousands more in various level of deployment. Initial deployment, enabled through FHWA (Federal Highway Administration) and state departments of transportation, focused on high-speed chargers to support long-distance travel, but more than $1.1 billion is available for community-based chargers. Nealer noted that a National Renewable Energy Laboratory study found that about 1.2 million public charging ports will be needed to reach the target of having 33 million EVs on the road by 2030. Of this total, approximately 1 million charging ports can be lower-speed level 2 units deployed at workplaces, multi-unit housing, retail locations, and home chargers throughout both urban and rural areas. Currently, there are some 192,000 charging ports in the United States.

Nealer said realizing a future where everyone can drive an EV requires both public and private investment. Private investment is happening with commitments from automakers, hotel chains, and numerous site hosts. Success, she said, will be achieving a national charging network that embodies the foundational principles of convenience and a great customer experience; affordability in an open market that fosters competition and innovation; reliability with a foundation for vehicle-grid integration; and equity where

chargers are available for any driver, any EV, and everywhere, while also creating jobs, supporting EV adoption, and reducing transportation emissions.

ZACHARY KOLODIN

Kolodin said the Bipartisan Infrastructure Law was not designed to close the nation's substantial infrastructure maintenance gap. Even before supply chain challenges that triggered cost increases and project delays, he thought the law could address approximately 10 percent of the deferred maintenance gap. In Michigan, for example, much of the infrastructure developed between 1930 and 1960, when the state experienced massive population growth, now needs significant attention.

One challenge, said Kolodin, arises from the fact that the design decisions made when this infrastructure was built differs from those that would be made today. For example, in the first half of the 20th century, communities built dual-purpose systems for both wastewater and stormwater that dumped untreated water into rivers, streams, and lakes. Today, those systems still exist and when it rains, stormwater flows into wastewater treatment plants and can overwhelm them. This was less of a problem 20 years ago, when 100-year storms were rare, but as the frequency of these major storms increase, so, too, do incidences where wastewater flows back onto city streets. Many communities, however, do not have the tax base to uncouple their systems by themselves.

Kolodin said transportation needs to largely focus on road pavement quality regarding highway transportation and one-time performance for rail and public transit systems. He noted that addressing roadway quality before it becomes critical saves about $6 for every dollar spent on early maintenance, typically before there is a 40 percent drop in roadway quality. The same calculation, he added, applies to bridge maintenance and other categories of infrastructure, where the return on investment on spending now versus spending in the future is on the order of four or five to one. Investments through the Bipartisan Infrastructure Law will help the nation stay on a fiscally sustainable track and helps states such as Michigan with serious deferred maintenance needs stay on track, said Kolodin.

Supporting the EV transportation system Nealer discussed requires charging stations, transmission infrastructure to support the distribution of electricity to those stations, and clean energy sources supplied by the grid. Meeting the clean electricity needs for such a system has struggled with siting challenges, with solar and wind installations rarely enjoying the same preemptory protections built into law for oil and natural gas. These challenges increase the costs of clean energy. To address this problem, Michigan has created a process by which developers can bring their clean energy projects to the Michigan Public Service Commission for an inclusive, deliberative process that applies the same standard for every project across the state, eliminating the patchwork of ever-shifting local regulations that Kolodin noted are often reacting to false narratives about the effects of clean energy on a local community.

Michigan, said Kolodin, believes that every community should have access to clean energy resources, and access to the jobs associated with building and maintaining these projects, and the state has created a variety of programs to empower communities to host these projects. The Renewable Ready Communities Program, funded by a $125 million grant from the Environmental Protection Agency, is one example. The state makes technical assistance available to help communities plan for these projects, and it has a program designed to help communities and developers turn brownfield sites into useable assets that create reliable, affordable power for communities. Solar installations, he added, can help additional

revenues for family farms. He noted that the state is building the supply chains to supply the solar industry in Michigan.

NAT FORD

Ford explained the Jacksonville Transit Authority (JTA) started as an expressway authority in charge of building roads and bridges, with it later assuming responsibility for public transportation in northeast Florida countries comprising fixed route bus service and paratransit services. JTA offers a standard paratransit service as well as a premium service that is more like a ride-share service that an individual can summon with a personal digital device. JTA also operates an automated monorail in downtown Jacksonville and a car and passenger ferry service linking communities across the St. Johns River. Ford noted JTA had received notice it won a $15.6 million federal award to purchase a second environmentally friendly ferry.

In addition, said Ford, JTA provides several door-to-door transportation options, including a free Door-to-Store service for residents in food deserts so they can get transportation to local markets with fresh produce and meat and the free My Ride 2 School service for middle, high school, and college students. The latter helps the community's schools that are facing a shortage of bus operators and bus drivers. Recently, this service set a new load record, carrying over 2,000 students in one day.

Ford said JTA developed its MyJTA app that passengers can use to check schedules and buy tickets. To ensure equity for the community's customers who lack bank accounts, MyJTA app users can use Cash App. He noted that once passengers who purchase single-day or single-ride passes hit the multiday thresholds of a 7-day or 30-day pass, the system caps their rides for the remainder of the month to ensure that all its users can benefit from discounted fares.

JTA's MOVE2027 strategic plan, which Ford said follows its previous 5-year plan it completed in three years, has seven strategic goals emphasizing safety and security, financial responsibility, employee success, customer satisfaction, and innovation to improve the quality of life in the community. One focus is on reducing fatalities and severe injuries from pedestrian, bicycle, and automobility accidents.

In 2014, said Ford, JTA received funding from a local option gas tax that enabled it to complete 27 mobility projects two years early. Completed projects included installing over 25 miles of sidewalks, 18 miles of bike lanes, five miles of trains, 74 pedestrian signals, 295 Americans with Disability Act ramps, and 36 traffic signals. As a result, an extension and expansion of the gas tax has provided an addition $500 million for transportation infrastructure projects, which will include major upgrades and enhancements to 111 bus stops in northwest Jacksonville neighborhoods, which are among the regions most underserved communities.

Recently, said Ford, Jacksonville received a $147 million grant to complete the Emerald Trail. This trail knits together a 30-mile network of bicycle and pedestrian trains encircling downtown Jacksonville. It will connect 14 historic neighborhoods, 18 schools, three hospitals, two colleges, and nearly 30 parks. JTA's signature project, called U^{2}C, will be the nation's first AV network for public transportation. Phase 1, which will launch in the summer of 2025, will create a three-mile, at-grade service in Jacksonville's downtown core powered by 14 AVs. Phase 2 will transform a two-mile elevated monorail into an elevated roadway

for AVs, and Phase 3 will extend the system into nearby neighborhoods. The finished project will create a 10-mile system connecting medical and educational facilities, residential neighborhoods, and businesses.

Ford noted the importance of talking about mobility in a holistic manner rather than playing one mode off another. JTA's local support, in the form of multiple gas tax extensions and expansions, comes from focuses on the spectrum of mobility that includes sidewalks and bike lanes as well as transit systems.

ZUBER MODERATED THE Q&A AND DISCUSSION BETWEEN PCAST MEMBERS AND NEALER, KOLODIN, AND FORD

SESSION: TRANSPORTATION INNOVATIONS LEADING TO OPPORTUNITIES

Edwin Olson explained that May Mobility develops autonomous driving technology and works with cities to deploy it to help solve transit problems and help with accessibility and equity. In his opinion, AVs can help address many transit problems, such as providing services for the 25 million Americans with a disability that interferes with their ability to access transportation or helping cities meet service demands in the face of not being able to hire enough drivers to do so. One in three to four transit agencies in the United States have had to reduce service because of hiring difficulties. AVs may also help reduce the number of traffic fatalities.

Olson noted that AVs can reduce the need for parking spaces and free land used for parking for green spaces, affordable housing, or small businesses. Parking, said Olson, is the most inefficient use of land space that humanity has ever developed. It is expensive to build and generates no revenue for a city. In Detroit, a third of the city's land use is dedicated to parking, and the cost of maintaining the infrastructure to support a car-dependent lifestyle contributed heavily to the city declaring bankruptcy in 2013.

A North Star for Olson is a quote from the mayor of Bogota, Colombia, who said that a developed country is not one where the poor have cars but where the rich use public transportation. Making that a reality means elevating what public transit is so people with the option of using cars will adopt public transportation as well.

Turning to the technical challenges facing AVs, Olson said there has been tremendous progress over the past 12 to 18 months, with several cities in the United States and Japan seeing AVs in use. May Mobility is in eight cities and will soon be in another eight. Another company, Waymo, has impressive deployments in Phoenix and San Francisco, he added. AI and machine learning have made this possible, but cost is still an issue. Olson noted the incredible expensive to collect that training data needed to power machine learning models that will operate AVs safely in an ever-changing urban environment, for example. To address that problem, Olson's company is excited about using online reinforcement learning, where the AV generates new training data as it drives in its operating environment. This approach has enabled May Mobility to reduce the cost of deploying its vehicles in different cities.

Olson raised social adoption as another challenge, that is, whether enough people will get into an AV. The good news, he said, is that in seven years of operating, nobody has refused to get into one of the company's vehicles. The key is to solve a real problem, such as not having to stand in the rain waiting for a bus. His team has worked with city partners who understand where the neighborhoods in their

communities are that need the most support. For example, May Mobility has worked in Grand Rapids, MN, an Iron Range community of approximately 14,000 people. It is not an affluent community, he explained, and owning a car is a severe financial hardship for many people in Grand Rapids. May Mobility deployed a fleet of wheelchair-accessible AVs that has garnered high consumer acceptance, with 91 percent of its riders being repeat users.

To drive the industry forward, Olson called for cities to develop funding mechanisms that will allow them to start experimenting with AVs. The federal government, he added, has been helpful by providing grants to cities to experiment with the technology and understand where they do and do not add value.

PAUL KRAJEWSKI

Krajewski said General Motors' (GM) aspiration goals are to have zero crashes, emissions, and congestion. Other speakers addressed electrification, so he focused on technologies addressing congestion and safety. These include display technologies that provide more information without the driver having to take their eyes off the road, a rear-view mirror connected to a rear camera, and GM's Super Cruise technology for autonomous driving. One thing that has helped with consumer adoption of these technologies is the ability to put consumers in virtual-reality simulators at its technology center in Warren, MI, to begin testing and exploring how consumers would experience and understand these new technologies. The company is now exploring the use of biosensing to quantify what that experience is as opposed solely relying on asking a person about their experience. While still confined to the laboratory, biosensing is providing good insights into how to better develop scenarios for test subjects. Krajewski said GM is also looking at brainwave technology that may enable someone with a disability to interact with or even operate a vehicle.

GM, said Krajewski, is leading an industry consortium developing a biofidelic model of the human body to address safety issues. This would resemble a virtual crash test dummy that incorporates human organs and human performance. One use would be to demonstrate the effects of different crash scenarios to new drivers. Another use would be to develop systems that would better protect drivers and provide feedback to a first responder. A virtual model would also enable morphing it to go from a small child to a large adult or even someone in a wheelchair to develop better restraint systems, for example.

Krajewski said GM has partnered with the University of Michigan and the local DoT office to leverage vehicle-generated data and optimize traffic lights and reduce congestion in the Detroit suburb of Birmingham, saving people 10 to 20 percent of their time on certain routes. GM now has a contract with Oakland County, MI, to optimize its traffic lights.

The Chips and Science Act has provided funding to explore vehicle-to-vehicle and vehicle-to-infrastructure communication as a means of reducing crashes and increasing safety. Achieving this, said Krajewski, requires a great deal of investment and public-private partnerships.

LUKE POLCYN

Polcyn noted that innovation is a necessary part of Detroit's strategy for enhancing the competitiveness of the automobile sector, diversifying the city's economy, creating a more resilient economic base, offering new job opportunities, and generating revenues the city can reinvest in

serves to benefit its citizens. The job of the mayor's office is to maximize the economic impact of innovation and maximize the opportunities for economic inclusion and growth. The work ahead of the city is to achieve the same success in the innovation economy it did building its industrial economy. It is the mayor's view that innovation-based job growth is the best and only way to raise the median income in Detroit and Michigan. Entrepreneurship is part of that strategy and a great economic equalizer.

Detroit, said Polcyn, views this work as more urgent than ever given that the city's traditional largest employers are facing significant domestic and international competition for the future of the auto industry. The city's task is to build an innovation system that helps the local automotive industry win that competition. That, he noted, means excelling in battery chemistry and electronics, hydrogen fuel cell technology, electric motors, power electronics, and software, and seizing opportunities in the advanced manufacturing sector. He added that rather than being a threat to Detroit's manufacturing workforce, advanced manufacturing can be the technology that can secure the future of Detroit's manufacturing workforce.

Polcyn said Detroit's human capital includes the nation's leading commercial and industrial design talent pool and the nation's highest concentration of engineers per capita. It also has 240,000 assembly and production workers that can serve as the skilled workforce needed for advanced manufacturing ventures to succeed. One legacy of the region's existing manufacturing base is a best-in-the-nation state and local workforce development and upskilling platform. This is a comparative advantage that situates the Detroit area to seize new opportunities and build a better future for the region.

PRABHAKAR MODERATED THE Q&A AND DISCUSSION BETWEEN PCAST MEMBERS AND OLSON, KRAJEWSKI, AND POLCYN

PUBLIC COMMENT

Ed Cackett, Wayne State University, did not provide comments but asked the speakers, as innovators, what they are looking for regarding undergraduate or graduate programs that prepare students to be successful, creative, and innovative. Krajewski replied that in addition to traditional academic classes, new classes could provide hand-on opportunities for students to work as a team and bring multidisciplinary expertise together to solve a problem, such as creating a solar car. Communication skills are also a huge differentiator, he said.

Olson said his company wants students with extensive hands-on experiences, but with a caveat. His experience teaching robotics courses is that students often are attracted to projects with an excessively large scope, such as building a robot that can do everything. This inevitably leads to students with a shallow understanding of each system in the robot rather than technical mastery. Polcyn echoed Krajewski's points about the importance of collaborative, experiential learning experiences that provide both technical and entrepreneurial skills.

CLOSING COMMENTS

Prabhakar, Arnold, and Zuber thanked the day's speakers and then adjourned the meeting.

MEETING ADJOURNED: 3:55 P. M. Eastern Time

I hereby certify that, to the best of my knowledge, the foregoing minutes are accurate and complete.

Frances Arnold, Ph.D.
Co-Chair
President's Council of Advisors on Science and Technology

Arati Prabhakar, Ph.D.
Co-Chair
President's Council of Advisors on Science and Technology

Maria Zuber, Ph.D.
Co-Chair
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