Report on Future Research Directions for the National Science Foundation in the Era of COVID-19

The Society for Industrial and Applied Mathematics (SIAM) presents the following recommendations on future research directions at the National Science Foundation (NSF) in light of the COVID-19 pandemic. SIAM is an international community of over 14,000 members from academia, industry, and government. Members come from many different disciplines, but all share an interest in applying current techniques of mathematics and computational science to solve real-world problems.

Background and Justification

The pandemic has illuminated new research needs to increase our nation's resilience and ability to overcome the pandemic, exposed major gaps in our research enterprise, and had a dramatic impact on the science and engineering workforce. Applied mathematics and computational science are critical components of a future research agenda to recover from the pandemic and build a more resilient future. The SIAM community stands ready to aid in this effort and seeks NSF support to mitigate the impacts of the pandemic on the research community. NSF support is central to continued innovation and economic recovery that will enable long-term U.S. competitiveness and ability to withstand challenges ahead.

This report was prepared by a task force established under the SIAM Committee on Science Policy (CSP), and its contents were also informed by separate information gathering activities.[1] These include discussions between CSP members and officials within the NSF Division of Mathematical Sciences (DMS), as well as a survey issued to the broader SIAM membership to solicit community input.[2] [3]

Overview of Recommendation Categories

Based on survey responses, outreach to DMS, and internal discussions, SIAM's findings and recommendations are organized into four categories:

Mathematics of Disaster Planning, Response, Recovery, and Resilience (MDPR3) – Research in applied mathematics and computational science can and should continue to be used to address the current pandemic through contributions to diagnostics, treatments, vaccines, forecasting, and studies of societal impacts. However, it is also critical that NSF look to support research now that can better prepare our country for future outbreaks and increase our overall resilience. Mathematical, computational, and data science research and modeling will be critical to laying the foundation for a more robust disaster planning and response regime by strengthening supply chain resilience and optimization, improving decision-making amid uncertainty, and understanding group dynamics in crises.

[1] A list of Task Force members can be found in Appendix A.

[2] Survey responses can be viewed at https://drive.google.com/file/d/1XNvg6ltCAIpMMTpc8o-098NjzD5JPXRD/view.

[3] A report prepared by the Working Group on Predictive Modeling and Uncertainty Quantification, NSF Advisory Committee on Cyberinfrastructure (ACCI), can be viewed at https://drive.google.com/file/d/1ho1w3tEcT4V5Un4pjSLJCNcnYM83F_Uz/view.

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Partnerships – Research areas outlined under MDPR3 require convergent and interdisciplinary partnerships across NSF. In addition, many areas of disaster response and mitigation suffer from a gap in the pipeline between research and operations. Because basic science and operational readiness have separate communities and stakeholders, bridging that divide requires cross-sectoral and interagency partnerships.

Infrastructure and Collaboration Tools – The pandemic has thrown into sharp relief both the promise and limitation of remote work. At the same time, the present situation offers an opportunity to develop ideas, informed by real world experience, for what the future of research looks like and what infrastructure and tools are needed to enable that vision.

Workforce Development – SIAM is especially concerned about the negative ramifications of this pandemic on students, post-docs, and early career researchers. Special focus should be given to those at the critical transition points, underrepresented and underserved groups hard hit by the pandemic, and primary caretakers who have faced especially challenging dynamics.

SIAM believes that these categories provide NSF with a well-rounded and comprehensive framework for leveraging applied mathematics and computational science to revamp its research enterprise in the wake of this crisis and addressing needs across its research portfolio. Additional details and recommendations for each category can be found below.

Detailed Recommendations

<u>Mathematics of Disaster Planning, Response, Recovery, and Resilience (MDPR3)</u>
The federal government has already put in place robust research funding to address the current pandemic in terms of diagnostics, treatments, vaccines, forecasting, and studies of societal impacts. These efforts should continue, and mathematics and computational science have an important role to play through many of these areas. Given that many of these efforts are well underway, and since basic research can take years to bear fruit, it is also critical that NSF look to support research now that can better prepare our country for future outbreaks and increase our overall resilience.

The applied mathematics and computational science community has the expertise and capacity to lay the groundwork for a more robust disaster planning and response regime. Mathematical, computational, and data science research and modeling will be critical to strengthening supply chain resilience and optimization, improving decision-making amid uncertainty, and understanding group dynamics amid crises. However, greater investment will be needed in the following areas to realize those goals:

- Analysis of risk, robustness, and quantification of uncertainty;
- Network science and network analysis;
- Secure and protected real-time data integration and analytics for accurate forecasting;
- Predictive and informed modeling of disease spread, control, and mitigation; and
- Mathematical foundations of artificial intelligence (AI) and machine learning as it applies to the topics above.

The task force notes that the list of research topics above is not meant to be exhaustive. However, each of these areas is broadly applicable to the specific challenges detailed below:

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- Modeling has played an important role in the current pandemic to understand SARS-COV-2, evaluate potential interventions, track outbreaks, and provide planning information for policy makers. However, the COVID-19 pandemic has shown the limitations of these tools. NSF should ensure strong support for research in modeling foundations and applied modeling efforts to enable better tools for computational research around all facets of the pandemic. For example, actionable epidemiological modeling, disaster modeling, and topological data analysis are key needs.
- Major challenges in the current pandemic can be traced to failures in manufacturing, supply chains, and logistics. NSF should support applied mathematics research in these areas to ensure more resilient capacity and distribution networks.
- The pandemic has demonstrated lack of robust emergency response systems that could rapidly build up testing and treatment capacity. NSF should support activities that advance modeling coupled with computational machine learning algorithms that can better assess resilience in systems, identify weaknesses, and point to stronger flexibility for rapid situational changes. There should be an investment in the understanding and amelioration of risk in networked systems.
- Under a pandemic or other emergency, policymakers must make critical decisions with limited information on quick timescales. NSF should support collaborative research between mathematicians and social scientists to advance understanding of group dynamics and decision-making in the presence of uncertainty, and to incorporate the influence of social behavior into mathematical models. Predictive science also needs to be advanced to better understand future risks and enable better planning. There needs to be an increased emphasis on the interpretation and communication of uncertainties.
- The current pandemic has exposed the major role that social dynamics and behavior play in limiting or expanding the spread of COVID-19 and the pandemic has also significantly impacted critical societal systems in education and work. Major foundational questions remain in modeling and computational understanding of these areas.
- The COVID-19 pandemic has highlighted many thorny issues related to privacy in terms of contract tracing and other technologies for mitigating the pandemic's spread. More research on methods to analyze data while preserving privacy would advance the ability to analyze health data and could be an avenue for better tracking technology.
- NSF should foster collaborations between core research divisions and the Directorate for Education and Human Resources to foster a greater understanding of the impact of online instruction and to develop best practices for teaching remotely. There is also an urgent need for the development of methods to teach students with disabilities in remote environments and overcome technology gaps in disadvantaged communities.

<u>Partnerships</u>

Almost all the areas of research mentioned above require convergent and interdisciplinary partnerships across NSF. In addition, many areas of disaster response and mitigation suffer from a gap in the pipeline between research and operations. Because basic science and operational readiness have separate communities and stakeholders, bridging that divide requires cross-sectoral and interagency partnerships.

- NSF should continue to fund convergent, cross-cutting, and NSF-wide partnerships to address research related to COVID-19 and future disasters. Partnerships between math and computational focused parts of NSF and every other directorate are valuable. One gap where much more could be done is partnerships with the Directorate for Social and Behavioral Sciences (SBE), which sits at the center of many of the decision-making and behavioral questions

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discussed above and where modeling tools and understanding are underdeveloped relative to other fields. As an example, SBE has partnered with the Directorate for Computer and Information Sciences and Engineering (CISE) and the Partnership for AI on a solicitation for research at the "intersection of the social and technical dimensions of AI."

- NSF has strong experience developing partnerships and should look to do so in areas of relevance to the COVID-19 pandemic and building resilience against future disasters. SIAM suggests the following principles for effective partnerships:
  - Connect the mathematical and computational science community to disciplines or agencies that lack strong connections, such as agencies within the Department of Health and Human Services besides the National Institutes of Health (NIH). This will be especially important to advance public health where partnerships are currently less robust than those with NIH or physical science agencies. These partnerships would help ensure that mathematical and computational research of relevance to public health is conducted and that advancements can be more rapidly translated into operational tools.
  - NSF should build on its many successful interagency partnership models. For example, NSF could adapt its Algorithms for Threat Detection program to address biological threats such as those tracked by the Center for Disease Control (CDC), Department of Defense Chemical-Biological Defense Program, or the Biomedical Advanced Research and Development Authority (BARDA). NSF has had success partnering with foundations such as in the NSF-Simons Centers for Deep Learning and could build on that model considering partners such as the Sloan Foundation, Kavli Foundation, Chan Zuckerberg Initiative, Gates Foundation, etc.
  - NIH partnerships could also be expanded to reach new institutes. For example, DMS could seek to replicate its successful partnerships with the National Institutes of General Medical Sciences (NIGMS) and National Library of Medicine (NLM) with the National Institute for Allergy and Infectious Disease (NIAID).
  - Focus on translatable and usable results while also addressing foundational research questions.
  - Partnerships to expand community focus on key research questions of importance to partners are essential as are partnerships to expand access to infrastructure or data for the research community.
- NSF's industry partnership programs do not always capture the unique needs of translating foundational or applied mathematics research. In many cases, industry partners lack the skills required to use research from a university partner or the funding required to enable development of initial research into more user-friendly technology. Within university-industry partnership programs, NSF should establish incentives to encourage industry partners to make corresponding investments in their own development enterprises to ensure that the research pursued by the university participant is meeting customer needs.
- The pandemic has exposed the global interconnected nature of today's world where international collaboration is critical. NSF should continue to support international partnerships through programs such as Accel-Net and Partnerships for International Research and Education.

Infrastructure and Collaboration Tools

The pandemic has thrown into sharp relief both the promise and limitation of remote work. At the same time, the present situation offers an opportunity to develop ideas, informed by real world experience, for what the future of research looks like in the applied mathematics and computational science community.

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- The pandemic has made clear how essential modeling and computing are to modern science and thus it is essential that our infrastructure meets the needs of the science and engineering community to enable transformative research.
- Many academic researchers have needed quick access to small amounts of computational resources that could be provided through the cloud. NSF should support ways to rapidly enable this access, perhaps as connected to RAPID grants. The partnership between NSF CISE and Amazon could serve as a potential example.
- There is a need to build a cyber-infrastructure to catalogue, store, access, parse, manage, and process data sets (de-identified or synthetic patient data, travel data, etc.), along with supporting digital management tools.
- NSF should reestablish the Group Infrastructure Grants (GIG) program. Established in 1994, GIG made awards to small groups of investigators to support access to infrastructure to enhance the research and educational environment. The primary beneficiaries of GIG were graduate students and postdocs, a cohort that has been particularly hard hit by the pandemic.
- NSF should explore mechanisms to support collaboration and convening among researchers, which have been lost due to cancellation of many conferences and annual meetings. Many groups have sought creative ways to enable collaboration even with the loss of face-to-face interaction but more research on new team science mechanisms and direct funding of convening amid the pandemic, as well as future crises, are needed.

Workforce Needs

SIAM is especially concerned about the negative ramifications of this pandemic on students, post-docs, and early career researchers. Special focus should be given to those at the critical transition points, underrepresented and underserved groups hit hard by the pandemic, and primary caretakers who have faced especially challenging dynamics.

- It is critical for NSF to continue to be flexible in its deadlines and dealings with the academic community. Students and post-docs may need extensions of their fellowships to ensure completion for any paused efforts or as a bridge to a very challenging hiring climate. Without addressing these issues, NSF risks losing a generation of STEM talent, which would be a huge loss to our innovation ecosystem.
- NSF should explore ways to adapt training programs, such as Research Experiences for Undergraduates, to virtual environments to ensure undergraduates can continue to have exposure to exciting research and prepare for STEM careers beyond their course work.
- Non-Academic Research Internships for Graduate Students (INTERN), Mathematical Sciences Graduate Internship (MSGI) and other programs that build connections between universities and federal labs and industry are critical to ensure continuity in the federal workforce. NSF should seek to build on these programs or adapt new mechanisms to support these pathways.
- The pandemic has upended whole industries and therefore will displace many workers even once society can return to post-pandemic life. NSF should invest in research on upskilling, reskilling, and community college education to ensure robust access to valuable education and training experiences for displaced workers. Mathematical and computational skills are increasingly needed in many jobs within the industries of the future. NSF should particularly look to enhance the building of these skills through certificate programs, Advanced Technological Education (ATE), or other creative mechanisms for developing new credentials. Programs supporting transitions between community colleges and four-year institutions would also be useful, including mentoring activities such as those previously supported by the Mentoring through Critical Transitions Program (MCTP).

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- Advancements in AI and machine learning have changed the landscape of mathematics and computational science, yet many in the math community do not have strong skills in these areas. NSF should support opportunities for researchers and faculty to build stronger skills. This recommendation and the one above may be addressed through programs such as the Data Science Corps.
- NSF should look to build on existing efforts towards ensuring robust computational thinking skills in K-12 students as these skills are increasingly needed in many disciplines and industries.
- As mentioned above, the pandemic has hit under-represented and under-served groups especially hard. It is imperative that NSF expand its focus on broadening participation. The Inclusion across the Nation of Communities of Learners of Underrepresented Discoverers in Engineering and Science (INCLUDES) initiative is a powerful model that could be expanded for this purpose. NSF should also carefully look at its review process to root out bias and build transparency.

APPENDIX A

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