NSF 24-569: Mathematical Foundations of Artificial Intelligence

Program Solicitation

Document Information

Document History

- **Posted:** May 1, 2024

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National Science Foundation
Directorate for Mathematical and Physical Sciences
Division of Mathematical Sciences
Directorate for Computer and Information Science and Engineering
Division of Computing and Communication Foundations
Division of Information and Intelligent Systems
Directorate for Engineering
Division of Civil, Mechanical and Manufacturing Innovation
Division of Electrical, Communications and Cyber Systems
Directorate for Social, Behavioral and Economic Sciences
Division of Social and Economic Sciences

Full Proposal Deadline(s) (due by 5 p.m. submitting organization's local time):

October 10, 2024

October 10, 2025

October 09, 2026

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Important Information And Revision Notes

Any proposal submitted in response to this solicitation should be submitted in accordance with the *NSF Proposal & Award Policies & Procedures Guide* (PAPPG) that is in effect for the relevant due date to which the proposal is being submitted. The NSF PAPPG is regularly revised and it is the responsibility of the proposer to ensure that the proposal meets the requirements specified in this solicitation and the applicable version of the PAPPG. Submitting a proposal prior to a specified deadline does not negate this requirement.

Summary Of Program Requirements

General Information

Program Title:

Mathematical Foundations of Artificial Intelligence (MFAI)

Synopsis of Program:

Machine Learning and Artificial Intelligence (AI) are enabling extraordinary scientific breakthroughs in fields ranging from protein folding, natural language processing, drug synthesis, and recommender systems to the discovery of novel engineering materials and products. These achievements lie at the confluence of mathematics, statistics, engineering and computer science, yet a clear explanation of the remarkable power and also the limitations of such AI systems has eluded scientists from all disciplines. Critical foundational gaps remain that, if not properly addressed, will soon limit advances in machine learning, curbing progress in artificial intelligence. It appears increasingly unlikely that these critical gaps can be surmounted with increased computational power and experimentation alone. Deeper mathematical understanding is essential to ensuring that AI can be harnessed to meet the future needs of society and enable broad scientific discovery, while forestalling the unintended consequences of a disruptive technology.

The National Science Foundation Directorates for Mathematical and Physical Sciences (MPS), Computer and Information Science and Engineering (CISE), Engineering (ENG), and Social, Behavioral and Economic Sciences (SBE) will jointly sponsor research collaborations consisting of mathematicians, statisticians, computer scientists, engineers, and social and behavioral scientists focused on the mathematical and theoretical foundations of AI. Research activities should focus on the most challenging mathematical and theoretical questions aimed at understanding the capabilities, limitations, and emerging properties of AI methods as well as the development of novel, and mathematically grounded, design and analysis principles for the current and next generation of AI approaches.

Specific research goals include: establishing a fundamental mathematical understanding of the factors determining the capabilities and limitations of current and emerging generations of AI systems, including, but not limited to, foundation models, generative models, deep learning, statistical learning, federated learning, and other evolving paradigms; the development of mathematically grounded design and analysis principles for the current and next generations of AI systems; rigorous approaches for characterizing and validating machine learning algorithms and their predictions; research enabling provably reliable, translational, general-purpose AI systems and algorithms; encouragement of new collaborations across this interdisciplinary research community and from diverse institutions.

The overall goal is to establish innovative and principled design and analysis approaches for AI technology using creative yet theoretically grounded mathematical and statistical frameworks, yielding explainable and interpretable models that can enable sustainable, socially responsible, and trustworthy AI.

Cognizant Program Officer(s):

Please note that the following information is current at the time of publishing. See program website for any updates to the points of contact.

- Stacey Levine, Program Director, MPS/DMS, telephone: (703) 292-2948, email: mfai@nsf.gov
- Eyad Abed, Program Director, ENG/ECCS, telephone: (703) 292-2303, email: mfai@nsf.gov
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- Reha M. Uzsoy, Program Director, ENG/CMMI, telephone: (703) 292-2681, email: mfai@nsf.gov
- Juan P. Wachs, Program Director, CISE/IIS, telephone: (703) 292-8714, email: mfai@nsf.gov
- Kenneth C. Whang, Program Director, CISE/IIS, telephone: (703) 292-5149, email: mfai@nsf.gov
- Joseph M. Whitmeyer, Program Director, SBE/SES, telephone: (703) 292-7808, email: mfai@nsf.gov

Applicable Catalog of Federal Domestic Assistance (CFDA) Number(s):

- 47.041 --- Engineering
- 47.049 --- Mathematical and Physical Sciences
- 47.070 --- Computer and Information Science and Engineering
- 47.075 --- Social Behavioral and Economic Sciences

Award Information

Anticipated Type of Award: Standard Grant or Continuing Grant

Estimated Number of Awards: 15

We anticipate making up to 15 awards in each competition. Each award size may vary and is expected to range from $500k to $1.5M total. Each award is expected to take place for a duration of 36 months. Award size is contingent upon the scope, scale and complexity of the proposed project. The number of awards will be subject to the availability of funds and quality of proposals received.

Anticipated Funding Amount: $8,500,000

Up to $8,500,000 per year is expected for new awards, subject to availability of funds and receipt of meritorious proposals.

Eligibility Information

Who May Submit Proposals:

Proposals may only be submitted by the following:

- Non-profit, non-academic organizations: Independent museums, observatories, research laboratories, professional societies and similar organizations located in the U.S. that are directly associated with educational or research activities.
- Institutions of Higher Education (IHEs) - Two- and four-year IHEs (including community colleges) accredited in, and having a campus located in the US, acting on behalf of their faculty members.

Who May Serve as PI:

As of the date the proposal is submitted, any PI, co-PI, or senior/key personnel must hold either:

- a tenured or tenure-track position, or
- a primary, full-time, paid appointment in a research or teaching position

at a US-based campus of an organization eligible to submit to this solicitation (see above), with exceptions granted for family or medical leave, as determined by the submitting organization. Individuals with primary appointments at for-profit non-academic organizations or at overseas branch campuses of U.S. institutions of higher education are not eligible.

Limit on Number of Proposals per Organization:

There are no restrictions or limits.

Limit on Number of Proposals per PI or co-PI: 1

A Principal Investigator (PI) or co-Principal Investigator (co-PI) can be part of no more than one proposal per deadline in response to this solicitation.

Proposal Preparation and Submission Instructions

A. Proposal Preparation Instructions

- **Letters of Intent:** Not required
- **Preliminary Proposal Submission:** Not required
- **Full Proposals:**
    - Full Proposals submitted via Research.gov: *NSF Proposal and Award Policies and Procedures Guide* (PAPPG) guidelines apply. The complete text of the PAPPG is available electronically on the NSF website at: https://www.nsf.gov/publications/pub_summ.jsp?ods_key=pappg.

- Full Proposals submitted via Grants.gov: *NSF Grants.gov Application Guide: A Guide for the Preparation and Submission of NSF Applications via Grants.gov* guidelines apply (Note: The *NSF Grants.gov Application Guide* is available on the Grants.gov website and on the NSF website at: https://www.nsf.gov/publications/pub_summ.jsp?ods_key=grantsgovguide).

B. Budgetary Information

- **Cost Sharing Requirements:**

  Inclusion of voluntary committed cost sharing is prohibited.

- **Indirect Cost (F&A) Limitations:**

  Not Applicable

- **Other Budgetary Limitations:**

  Not Applicable

C. Due Dates

- **Full Proposal Deadline(s)** (due by 5 p.m. submitting organization's local time):

  October 10, 2024

  October 10, 2025

  October 09, 2026

Proposal Review Information Criteria

Merit Review Criteria:

National Science Board approved criteria. Additional merit review criteria apply. Please see the full text of this solicitation for further information.

Award Administration Information

Award Conditions:

Standard NSF award conditions apply.

Reporting Requirements:

Standard NSF reporting requirements apply.

I. Introduction

Machine Learning and Artificial Intelligence (AI) are enabling extraordinary scientific breakthroughs in fields ranging from protein folding, natural language processing, drug synthesis, and recommender systems to the discovery of novel engineering materials and products. While these achievements lie at the confluence of mathematics, statistics, engineering, and computer science, a clear explanation of the remarkable power and limitations of such AI systems has eluded scientists from all disciplines. Critical foundational gaps remain that, if not properly addressed, will soon limit advances in machine learning, curbing progress in artificial intelligence. It appears increasingly unlikely that these critical gaps can be surmounted with increased computational power and experimentation alone. Deeper mathematical understanding is essential to ensuring that AI can be harnessed to meet future needs of society and enable broad scientific discovery, while forestalling the unintended consequences of a disruptive technology.

NSF's previous investments in the Mathematical and Scientific Foundations of Deep Learning (MoDL) program (NSF 20-540), the Stimulating Collaborative Advances Leveraging Expertise in the Mathematical and Scientific Foundations of Deep Learning (SCALE MoDL) program (NSF 21-561), the TRIPODS program (NSF 19-604), Harnessing the Data Revolution, and the Foundations of Machine Learning theme within the AI Institutes (NSF 20-503) have yielded important advances in understanding the mathematical, scientific, and theoretical foundations of deep learning, machine learning, and data science. Still, the tremendous body of AI knowledge and practice currently rests on a surprisingly limited mathematical foundation. Untapped and under-explored mathematical constructs have the potential to provide paradigm-changing approaches leading to more accurate, more robust, and less data- and computationally-hungry approaches.

The 2023 update to the National Artificial Intelligence Research and Development Strategic Plan highlights the need for "Understanding Theoretical Capabilities and Limitations of AI." Extending the mathematical and theoretical foundations underpinning AI will be essential for both understanding the successes and failures of current generation machine learning and developing the next generation that have better explainability, transferability, generalizability, and scalability. Such extensions will be critical for reliable, trusted AI methodologies and may offer significant reductions in implementation costs and better integration of domain-specific constraints. This could lead to a mathematically rigorous understanding of how generalizability and bias depend on the amount, quality, diversity, and fusion of data sources. For example, it could elucidate the factors affecting the double descent phenomenon of over-parameterized machine learning models, the dynamics and convergence of training such models, the resilience of such models to pruning, the success of synthetic data augmentation and in-context learning of transformers, and other important and timely questions. As the computer science and engineering communities push the limits of AI capabilities, the deep questions and concerns surrounding the value of inference from these models, as well as the associated risks, including ethical risks and potential human and social consequences, can only be addressed by making advances in the mathematical and theoretical foundations underlying these methods.

II. Program Description

MFAI aims to support research focused on the most challenging theoretical questions aimed at understanding the capabilities, limitations, and emerging properties of AI methods as well as the development of novel, mathematically grounded design and analysis principles for the current and next generations of AI. PI teams should collectively possess appropriate expertise drawn from mathematics/statistics, computer science, engineering, and social and behavioral sciences, as appropriate to the project. The scientific focus must be on the mathematical and theoretical foundations, but relevance to application domains where the mathematical advances may lead to significantly new capabilities or a deeper understanding of existing empirical observations should be addressed. Collaboration between theoretical and empirical scientists is highly encouraged.

Specific research goals are:

- A fundamental mathematical understanding of the factors determining the capabilities and limitations of current and emerging AI systems, including, but not limited to, foundation models, generative models, deep learning, statistical learning, federated learning, and other evolving paradigms;
- The development of mathematically grounded design and analysis principles for the current and next generations of AI;
- Rigorous approaches for characterizing and validating machine learning algorithms and their predictions, as well as research enabling provably reliable, translational, general-purpose AI systems and algorithms;
- Encouragement of new collaborations across this interdisciplinary research community and from diverse institutions.

Opportunities for advancing the mathematical foundations of modern AI include, but are not limited to, statistical inference and methodology, formal and symbolic logic, topology, complexity theory, algebraic geometry, representation theory, and analysis approaches such as dynamical systems, partial differential equations, mean field theory, approximation theory, and optimization theory, which, in turn, could facilitate the interpretability, transferability, generalizability, and scalability of AI.

Successful proposals will describe an actionable approach for advancing the mathematical and theoretical foundations of the current and/or next generation of artificial intelligence methodologies through targeting at least one key technical obstacle. Successful proposals will also make clear the innovative mathematical and theoretical contributions that will be addressed in the project. Proposals should clearly articulate the challenges to be addressed, the technical approaches to be taken to address these challenges, and discuss why the proposed technical approaches are viable, along with alternative approaches that might be adopted in the event of negative outcomes. Each proposal must clearly demonstrate substantial collaborative contributions from team members with complementary expertise and should highlight how the complementary expertise of the team provides a unique opportunity for progress. Each project team should also contribute to the development of the diverse, multidisciplinary research workforce that will continue to advance the field in the future. This will be through the research involvement of students, and/or postdoctoral associates from across the multi-disciplinary spectrum of relevant areas.

This program welcomes the submission of proposals that include the participation as e.g., PI, co-PI, senior/key personnel, postdoctoral scholars, graduate or undergraduate students, or other trainees from the full spectrum of diverse talent in STEM, including members of historically under-represented or under-served populations. It also includes diverse institutions including Minority-Serving Institutions (MSIs), Primarily Undergraduate Institutions (PUIs), and two-year colleges, and major research institutions. Proposals from EPSCoR (Established Program to Stimulate Competitive Research) jurisdictions are especially encouraged.

One or more award participants, including the project Principal Investigator (PI), will be expected to attend a PI meeting each year of the award to exchange ideas, effective practices, assessment strategies, as well as challenges.

III. Award Information

Anticipated Type of Award: Continuing Grant or Standard Grant

Estimated Number of Awards: up to 15

We anticipate making up to 15 awards in each competition. Each award size may vary and is expected to range from $500k to $1.5M total. Each award is expected to take place for a duration of 36 months. Award size is contingent upon the scope, scale and complexity of the proposed project. The number of awards will be subject to the availability of funds and quality of proposals received.

Anticipated Funding Amount: $8,500,000

Up to $8,500,000 per year is expected for new awards, subject to availability of funds and receipt of meritorious proposals.

IV. Eligibility Information

Who May Submit Proposals:

Proposals may only be submitted by the following:

- Non-profit, non-academic organizations: Independent museums, observatories, research laboratories, professional societies and similar organizations located in the U.S. that are directly associated with educational or research activities.
- Institutions of Higher Education (IHEs) - Two- and four-year IHEs (including community colleges) accredited in, and having a campus located in the US, acting on behalf of their faculty members.

Who May Serve as PI:

As of the date the proposal is submitted, any PI, co-PI, or senior/key personnel must hold either:

- a tenured or tenure-track position, or

- a primary, full-time, paid appointment in a research or teaching position

at a US-based campus of an organization eligible to submit to this solicitation (see above), with exceptions granted for family or medical leave, as determined by the submitting organization. Individuals with primary appointments at for-profit non-academic organizations or at overseas branch campuses of U.S. institutions of higher education are not eligible.

Limit on Number of Proposals per Organization:

There are no restrictions or limits.

Limit on Number of Proposals per PI or co-PI: 1

A Principal Investigator (PI) or co-Principal Investigator (co-PI) can be part of no more than one proposal per deadline in response to this solicitation.

V. Proposal Preparation And Submission Instructions

A. Proposal Preparation Instructions

Full Proposal Preparation Instructions: Proposers may opt to submit proposals in response to this Program Solicitation via Research.gov or Grants.gov.

- Full Proposals submitted via Research.gov: Proposals submitted in response to this program solicitation should be prepared and submitted in accordance with the general guidelines contained in the *NSF Proposal and Award Policies and Procedures Guide* (PAPPG). The complete text of the PAPPG is available electronically on the NSF website at: https://www.nsf.gov/publications/pub_summ.jsp?ods_key=pappg. Paper copies of the PAPPG may be obtained from the NSF Publications Clearinghouse, telephone (703) 292-8134 or by e-mail from nsfpubs@nsf.gov. The Prepare New Proposal setup will prompt you for the program solicitation number.
- Full proposals submitted via Grants.gov: Proposals submitted in response to this program solicitation via Grants.gov should be prepared and submitted in accordance with the *NSF Grants.gov Application Guide: A Guide for the Preparation and Submission of NSF Applications via Grants.gov*. The complete text of the *NSF Grants.gov Application Guide* is available on the Grants.gov website and on the NSF website at: (https://www.nsf.gov/publications/pub_summ.jsp?ods_key=grantsgovguide). To obtain copies of the Application Guide and Application Forms Package, click on the Apply tab on the Grants.gov site, then click on the Apply Step 1: Download a Grant Application Package and Application Instructions link and enter the funding opportunity number, (the program solicitation number without the NSF prefix) and press the Download Package button. Paper copies of the Grants.gov Application Guide also may be obtained from the NSF Publications Clearinghouse, telephone (703) 292-8134 or by e-mail from nsfpubs@nsf.gov.

In determining which method to utilize in the electronic preparation and submission of the proposal, please note the following:

Collaborative Proposals. All collaborative proposals submitted as separate submissions from multiple organizations must be submitted via Research.gov. PAPPG Chapter II.E.3 provides additional information on collaborative proposals.

See PAPPG Chapter II.D.2 for guidance on the required sections of a full research proposal submitted to NSF. Please note that the proposal preparation instructions provided in this program solicitation may deviate from the PAPPG instructions.

***Title**:* To facilitate timely processing, the title of the proposed project should begin with "**MFAI:**". When you submit a proposal as part of a set of collaborative proposals, the title of the proposal should begin with "**Collaborative Research: MFAI:**" Please note that if submitting via Research.gov, the system will automatically insert the prepended title "Collaborative Research" when the collaborative set of proposals is created. All proposals in a group of separately submitted collaborative proposals should have the same title and should be submitted to the MFAI program.

Supplementary Documentation: Since the success of collaborative research efforts is known to depend on thoughtful coordination mechanisms that regularly bring together the various participants of the project, a **Collaboration Plan** is required, even when the investigators are affiliated with the same institution. Up to two pages are allowed for Collaboration Plans and they must be submitted as a document under Supplementary Documents. The length and level of detail provided in the Collaboration Plan should be commensurate with the complexity of the proposed project. Collaboration Plans and proposed budgets should demonstrate that key personnel, and especially lead PIs, have allocated adequate time for both their individual technical contributions and the leadership of collaborative activities necessary to realize the synergistic effects of multidisciplinary research.

B. Budgetary Information

Cost Sharing:

Inclusion of voluntary committed cost sharing is prohibited.

Budget Preparation Instructions:

All proposals are required to include as a line item in their budgets, the travel expenses associated with participation in the yearly PI Meeting.

C. Due Dates

- **Full Proposal Deadline(s)** (due by 5 p.m. submitting organization's local time):

  October 10, 2024

  October 10, 2025

  October 09, 2026

D. Research.gov/Grants.gov Requirements

For Proposals Submitted Via Research.gov:

To prepare and submit a proposal via Research.gov, see detailed technical instructions available at: https://www.research.gov/research-portal/appmanager/base/desktop?_nfpb=true&_pageLabel=research_node_display&_nodePath=/researchGov/Service/Desktop/ProposalPreparationa For Research.gov user support, call the Research.gov Help Desk at 1-800-381-1532 or e-mail rgov@nsf.gov. The Research.gov Help Desk answers general technical questions related to the use of the Research.gov system. Specific questions related to this program solicitation should be referred to the NSF program staff contact(s) listed in Section VIII of this funding opportunity.

For Proposals Submitted Via Grants.gov:

Before using Grants.gov for the first time, each organization must register to create an institutional profile. Once registered, the applicant's organization can then apply for any federal grant on the Grants.gov website. Comprehensive information about using Grants.gov is available on the Grants.gov Applicant Resources webpage: https://www.grants.gov/web/grants/applicants.html. In addition, the NSF Grants.gov Application Guide (see link in Section V.A) provides instructions regarding the technical preparation of proposals via Grants.gov. For Grants.gov user support, contact the Grants.gov Contact Center at 1-800-518-4726 or by email: support@grants.gov. The Grants.gov Contact Center answers general technical questions related to the use of Grants.gov. Specific questions related to this program solicitation should be referred to the NSF program staff contact(s) listed in Section VIII of this solicitation.

Submitting the Proposal: Once all documents have been completed, the Authorized Organizational Representative (AOR) must submit the application to Grants.gov and verify the desired funding opportunity and agency to which the application is submitted. The AOR must then sign and submit the

application to Grants.gov. The completed application will be transferred to Research.gov for further processing.

The NSF Grants.gov Proposal Processing in Research.gov informational page provides submission guidance to applicants and links to helpful resources including the NSF Grants.gov Application Guide, Grants.gov Proposal Processing in Research.gov how-to guide, and Grants.gov Submitted Proposals Frequently Asked Questions. Grants.gov proposals must pass all NSF pre-check and post-check validations in order to be accepted by Research.gov at NSF.

When submitting via Grants.gov, NSF strongly recommends applicants initiate proposal submission at least five business days in advance of a deadline to allow adequate time to address NSF compliance errors and resubmissions by 5:00 p.m. submitting organization's local time on the deadline. Please note that some errors cannot be corrected in Grants.gov. Once a proposal passes pre-checks but fails any post-check, an applicant can only correct and submit the in-progress proposal in Research.gov.

Proposers that submitted via Research.gov may use Research.gov to verify the status of their submission to NSF. For proposers that submitted via Grants.gov, until an application has been received and validated by NSF, the Authorized Organizational Representative may check the status of an application on Grants.gov. After proposers have received an e-mail notification from NSF, Research.gov should be used to check the status of an application.

VI. NSF Proposal Processing And Review Procedures

Proposals received by NSF are assigned to the appropriate NSF program for acknowledgement and, if they meet NSF requirements, for review. All proposals are carefully reviewed by a scientist, engineer, or educator serving as an NSF Program Officer, and usually by three to ten other persons outside NSF either as *ad hoc* reviewers, panelists, or both, who are experts in the particular fields represented by the proposal. These reviewers are selected by Program Officers charged with oversight of the review process. Proposers are invited to suggest names of persons they believe are especially well qualified to review the proposal and/or persons they would prefer not review the proposal. These suggestions may serve as one source in the reviewer selection process at the Program Officer's discretion. Submission of such names, however, is optional. Care is taken to ensure that reviewers have no conflicts of interest with the proposal. In addition, Program Officers may obtain comments from site visits before recommending final action on proposals. Senior NSF staff further review recommendations for awards. A flowchart that depicts the entire NSF proposal and award process (and associated timeline) is included in PAPPG Exhibit III-1.

A comprehensive description of the Foundation's merit review process is available on the NSF website at: https://www.nsf.gov/bfa/dias/policy/merit_review/.

Proposers should also be aware of core strategies that are essential to the fulfillment of NSF's mission, as articulated in *Leading the World in Discovery and Innovation, STEM Talent Development and the Delivery of Benefits from Research - NSF Strategic Plan for Fiscal Years (FY) 2022 - 2026*. These strategies are integrated in the program planning and implementation process, of which proposal review is one part. NSF's mission is particularly well-implemented through the integration of research and education and broadening participation in NSF programs, projects, and activities.

One of the strategic objectives in support of NSF's mission is to foster integration of research and education through the programs, projects, and activities it supports at academic and research institutions. These institutions must recruit, train, and prepare a diverse STEM workforce to advance the frontiers of science and participate in the U.S. technology-based economy. NSF's contribution to the national innovation ecosystem is to provide cutting-edge research under the guidance of the Nation's most creative scientists and engineers. NSF also supports development of a strong science, technology, engineering, and mathematics (STEM) workforce by investing in building the knowledge that informs improvements in STEM teaching and learning.

NSF's mission calls for the broadening of opportunities and expanding participation of groups, institutions, and geographic regions that are underrepresented in STEM disciplines, which is essential to the health and vitality of science

and engineering. NSF is committed to this principle of diversity and deems it central to the programs, projects, and activities it considers and supports.

A. Merit Review Principles and Criteria

The National Science Foundation strives to invest in a robust and diverse portfolio of projects that creates new knowledge and enables breakthroughs in understanding across all areas of science and engineering research and education. To identify which projects to support, NSF relies on a merit review process that incorporates consideration of both the technical aspects of a proposed project and its potential to contribute more broadly to advancing NSF's mission "to promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense; and for other purposes." NSF makes every effort to conduct a fair, competitive, transparent merit review process for the selection of projects.

1. Merit Review Principles

These principles are to be given due diligence by PIs and organizations when preparing proposals and managing projects, by reviewers when reading and evaluating proposals, and by NSF program staff when determining whether or not to recommend proposals for funding and while overseeing awards. Given that NSF is the primary federal agency charged with nurturing and supporting excellence in basic research and education, the following three principles apply:

- All NSF projects should be of the highest quality and have the potential to advance, if not transform, the frontiers of knowledge.
- NSF projects, in the aggregate, should contribute more broadly to achieving societal goals. These "Broader Impacts" may be accomplished through the research itself, through activities that are directly related to specific research projects, or through activities that are supported by, but are complementary to, the project. The project activities may be based on previously established and/or innovative methods and approaches, but in either case must be well justified.
- Meaningful assessment and evaluation of NSF funded projects should be based on appropriate metrics, keeping in mind the likely correlation between the effect of broader impacts and the resources provided to implement projects. If the size of the activity is limited, evaluation of that activity in isolation is not likely to be meaningful. Thus, assessing the effectiveness of these activities may best be done at a higher, more aggregated, level than the individual project.

With respect to the third principle, even if assessment of Broader Impacts outcomes for particular projects is done at an aggregated level, PIs are expected to be accountable for carrying out the activities described in the funded project. Thus, individual projects should include clearly stated goals, specific descriptions of the activities that the PI intends to do, and a plan in place to document the outputs of those activities.

These three merit review principles provide the basis for the merit review criteria, as well as a context within which the users of the criteria can better understand their intent.

2. Merit Review Criteria

All NSF proposals are evaluated through use of the two National Science Board approved merit review criteria. In some instances, however, NSF will employ additional criteria as required to highlight the specific objectives of certain programs and activities.

The two merit review criteria are listed below. **Both** criteria are to be given **full consideration** during the review and decision-making processes; each criterion is necessary but neither, by itself, is sufficient. Therefore, proposers must fully address both criteria. (PAPPG Chapter II.D.2.d(i). contains additional information for use by proposers in development of the Project Description section of the proposal). Reviewers are strongly encouraged to review the criteria, including PAPPG Chapter II.D.2.d(i), prior to the review of a proposal.

When evaluating NSF proposals, reviewers will be asked to consider what the proposers want to do, why they want to do it, how they plan to do it, how they will know if they succeed, and what benefits could accrue if the project is successful.

These issues apply both to the technical aspects of the proposal and the way in which the project may make broader contributions. To that end, reviewers will be asked to evaluate all proposals against two criteria:

- **Intellectual Merit:** The Intellectual Merit criterion encompasses the potential to advance knowledge; and
- **Broader Impacts:** The Broader Impacts criterion encompasses the potential to benefit society and contribute to the achievement of specific, desired societal outcomes.

The following elements should be considered in the review for both criteria:

1. What is the potential for the proposed activity to
    a. Advance knowledge and understanding within its own field or across different fields (Intellectual Merit); and
    b. Benefit society or advance desired societal outcomes (Broader Impacts)?
2. To what extent do the proposed activities suggest and explore creative, original, or potentially transformative concepts?
3. Is the plan for carrying out the proposed activities well-reasoned, well-organized, and based on a sound rationale? Does the plan incorporate a mechanism to assess success?
4. How well qualified is the individual, team, or organization to conduct the proposed activities?
5. Are there adequate resources available to the PI (either at the home organization or through collaborations) to carry out the proposed activities?

Broader impacts may be accomplished through the research itself, through the activities that are directly related to specific research projects, or through activities that are supported by, but are complementary to, the project. NSF values the advancement of scientific knowledge and activities that contribute to achievement of societally relevant outcomes. Such outcomes include, but are not limited to: full participation of women, persons with disabilities, and other underrepresented groups in science, technology, engineering, and mathematics (STEM); improved STEM education and educator development at any level; increased public scientific literacy and public engagement with science and technology; improved well-being of individuals in society; development of a diverse, globally competitive STEM workforce; increased partnerships between academia, industry, and others; improved national security; increased economic competitiveness of the United States; and enhanced infrastructure for research and education.

Proposers are reminded that reviewers will also be asked to review the Data Management and Sharing Plan and the Mentoring Plan, as appropriate.

Additional Solicitation Specific Review Criteria

In addition to the National Science Board merit review criteria, reviewers will be asked to assess how well the proposal addresses the following aspects:

- Is there is a compelling collaboration plan which clearly articulates the added value and complementary expertise spanning the necessary areas of knowledge?
- To what extent does the proposal clearly articulate the mathematical and theoretical innovations?

B. Review and Selection Process

Proposals submitted in response to this program solicitation will be reviewed by Ad hoc Review and/or Panel Review.

Reviewers will be asked to evaluate proposals using two National Science Board approved merit review criteria and, if applicable, additional program specific criteria. A summary rating and accompanying narrative will generally be completed and submitted by each reviewer and/or panel. The Program Officer assigned to manage the proposal's review will consider the advice of reviewers and will formulate a recommendation.

After scientific, technical and programmatic review and consideration of appropriate factors, the NSF Program Officer recommends to the cognizant Division Director whether the proposal should be declined or recommended for award. NSF strives to be able to tell proposers whether their proposals have been declined or recommended for funding within six months. Large or particularly complex proposals or proposals from new recipients may require additional review and processing time. The time interval begins on the deadline or target date, or receipt date, whichever is later. The interval ends when the Division Director acts upon the Program Officer's recommendation.

After programmatic approval has been obtained, the proposals recommended for funding will be forwarded to the Division of Grants and Agreements or the Division of Acquisition and Cooperative Support for review of business, financial, and policy implications. After an administrative review has occurred, Grants and Agreements Officers perform the processing and issuance of a grant or other agreement. Proposers are cautioned that only a Grants and Agreements Officer may make commitments, obligations or awards on behalf of NSF or authorize the expenditure of funds. No commitment on the part of NSF should be inferred from technical or budgetary discussions with a NSF Program Officer. A Principal Investigator or organization that makes financial or personnel commitments in the absence of a grant or cooperative agreement signed by the NSF Grants and Agreements Officer does so at their own risk.

Once an award or declination decision has been made, Principal Investigators are provided feedback about their proposals. In all cases, reviews are treated as confidential documents. Verbatim copies of reviews, excluding the names of the reviewers or any reviewer-identifying information, are sent to the Principal Investigator/Project Director by the Program Officer. In addition, the proposer will receive an explanation of the decision to award or decline funding.

VII. Award Administration Information

A. Notification of the Award

Notification of the award is made to *the submitting organization* by an NSF Grants and Agreements Officer. Organizations whose proposals are declined will be advised as promptly as possible by the cognizant NSF Program administering the program. Verbatim copies of reviews, not including the identity of the reviewer, will be provided automatically to the Principal Investigator. (See Section VI.B. for additional information on the review process.)

B. Award Conditions

An NSF award consists of: (1) the award notice, which includes any special provisions applicable to the award and any numbered amendments thereto; (2) the budget, which indicates the amounts, by categories of expense, on which NSF has based its support (or otherwise communicates any specific approvals or disapprovals of proposed expenditures); (3) the proposal referenced in the award notice; (4) the applicable award conditions, such as Grant General Conditions (GC-1)*; or Research Terms and Conditions* and (5) any announcement or other NSF issuance that may be incorporated by reference in the award notice. Cooperative agreements also are administered in accordance with NSF Cooperative Agreement Financial and Administrative Terms and Conditions (CA-FATC) and the applicable Programmatic Terms and Conditions. NSF awards are electronically signed by an NSF Grants and Agreements Officer and transmitted electronically to the organization via e-mail.

*These documents may be accessed electronically on NSF's Website at https://www.nsf.gov/awards/managing/award_conditions.jsp?org=NSF. Paper copies may be obtained from the NSF Publications Clearinghouse, telephone (703) 292-8134 or by e-mail from nsfpubs@nsf.gov.

More comprehensive information on NSF Award Conditions and other important information on the administration of NSF awards is contained in the NSF *Proposal & Award Policies & Procedures Guide* (PAPPG) Chapter VII, available electronically on the NSF Website at https://www.nsf.gov/publications/pub_summ.jsp?ods_key=pappg.

Administrative and National Policy Requirements

Build America, Buy America

As expressed in Executive Order 14005, Ensuring the Future is Made in All of America by All of America's Workers (86 FR 7475), it is the policy of the executive branch to use terms and conditions of Federal financial assistance awards to maximize, consistent with law, the use of goods, products, and materials produced in, and services offered in, the United States.

Consistent with the requirements of the Build America, Buy America Act (Pub. L. 117-58, Division G, Title IX, Subtitle A, November 15, 2021), no funding made available through this funding opportunity may be obligated for an award unless all iron, steel, manufactured products, and construction materials used in the project are produced in the United States. For additional information, visit NSF's Build America, Buy America webpage.

C. Reporting Requirements

For all multi-year grants (including both standard and continuing grants), the Principal Investigator must submit an annual project report to the cognizant Program Officer no later than 90 days prior to the end of the current budget period. (Some programs or awards require submission of more frequent project reports). No later than 120 days following expiration of a grant, the PI also is required to submit a final annual project report, and a project outcomes report for the general public.

Failure to provide the required annual or final annual project reports, or the project outcomes report, will delay NSF review and processing of any future funding increments as well as any pending proposals for all identified PIs and co-PIs on a given award. PIs should examine the formats of the required reports in advance to assure availability of required data.

PIs are required to use NSF's electronic project-reporting system, available through Research.gov, for preparation and submission of annual and final annual project reports. Such reports provide information on accomplishments, project participants (individual and organizational), publications, and other specific products and impacts of the project. Submission of the report via Research.gov constitutes certification by the PI that the contents of the report are accurate and complete. The project outcomes report also must be prepared and submitted using Research.gov. This report serves as a brief summary, prepared specifically for the public, of the nature and outcomes of the project. This report will be posted on the NSF website exactly as it is submitted by the PI.

More comprehensive information on NSF Reporting Requirements and other important information on the administration of NSF awards is contained in the *NSF Proposal & Award Policies & Procedures Guide* (PAPPG) Chapter VII, available electronically on the NSF Website at https://www.nsf.gov/publications/pub_summ.jsp?ods_key=pappg.

VIII. Agency Contacts

Please note that the program contact information is current at the time of publishing. See program website for any updates to the points of contact.

General inquiries regarding this program should be made to:

- Stacey Levine, Program Director, MPS/DMS, telephone: (703) 292-2948, email: mfai@nsf.gov
- Eyad Abed, Program Director, ENG/ECCS, telephone: (703) 292-2303, email: mfai@nsf.gov
- Yulia Gel, Program Director, MPS/DMS, telephone: (703) 292-7888, email: mfai@nsf.gov
- Alfred Hero, Program Director, CISE/CCF, telephone: (703) 292-8910, email: mfai@nsf.gov
- Anthony Kuh, Program Director, ENG/ECCS, telephone: (703) 292-4714, email: mfai@nsf.gov
- Tracy J. Kimbrel, telephone: (703) 292-8910, email: mfai@nsf.gov
- Phillip A. Regalia, Program Director, CISE/CCF, telephone: (703) 292-2981, email: mfai@nsf.gov
- Christopher W. Stark, Program Director, MPS/DMS, telephone: (703) 292-4869, email: mfai@nsf.gov
- Reha M. Uzsoy, Program Director, ENG/CMMI, telephone: (703) 292-2681, email: mfai@nsf.gov
- Juan P. Wachs, Program Director, CISE/IIS, telephone: (703) 292-8714, email: mfai@nsf.gov

- Kenneth C. Whang, Program Director, CISE/IIS, telephone: (703) 292-5149, email: mfai@nsf.gov
- Joseph M. Whitmeyer, Program Director, SBE/SES, telephone: (703) 292-7808, email: mfai@nsf.gov

For questions related to the use of NSF systems contact:

- NSF Help Desk: 1-800-381-1532
- Research.gov Help Desk e-mail: rgov@nsf.gov

For questions relating to Grants.gov contact:

- Grants.gov Contact Center: If the Authorized Organizational Representatives (AOR) has not received a confirmation message from Grants.gov within 48 hours of submission of application, please contact via telephone: 1-800-518-4726; e-mail: support@grants.gov.

IX. Other Information

The NSF website provides the most comprehensive source of information on NSF Directorates (including contact information), programs and funding opportunities. Use of this website by potential proposers is strongly encouraged. In addition, "NSF Update" is an information-delivery system designed to keep potential proposers and other interested parties apprised of new NSF funding opportunities and publications, important changes in proposal and award policies and procedures, and upcoming NSF Grants Conferences. Subscribers are informed through e-mail or the user's Web browser each time new publications are issued that match their identified interests. "NSF Update" also is available on NSF's website.

Grants.gov provides an additional electronic capability to search for Federal government-wide grant opportunities. NSF funding opportunities may be accessed via this mechanism. Further information on Grants.gov may be obtained at https://www.grants.gov.

About The National Science Foundation

The National Science Foundation (NSF) is an independent Federal agency created by the National Science Foundation Act of 1950, as amended (42 USC 1861-75). The Act states the purpose of the NSF is "to promote the progress of science; [and] to advance the national health, prosperity, and welfare by supporting research and education in all fields of science and engineering."

NSF funds research and education in most fields of science and engineering. It does this through grants and cooperative agreements to more than 2,000 colleges, universities, K-12 school systems, businesses, informal science organizations and other research organizations throughout the US. The Foundation accounts for about one-fourth of Federal support to academic institutions for basic research.

NSF receives approximately 55,000 proposals each year for research, education and training projects, of which approximately 11,000 are funded. In addition, the Foundation receives several thousand applications for graduate and postdoctoral fellowships. The agency operates no laboratories itself but does support National Research Centers, user facilities, certain oceanographic vessels and Arctic and Antarctic research stations. The Foundation also supports cooperative research between universities and industry, US participation in international scientific and engineering efforts, and educational activities at every academic level.

Facilitation Awards for Scientists and Engineers with Disabilities (FASED) provide funding for special assistance or equipment to enable persons with disabilities to work on NSF-supported projects. See the *NSF Proposal & Award Policies & Procedures Guide* Chapter II.F.7 for instructions regarding preparation of these types of proposals.

The National Science Foundation has Telephonic Device for the Deaf (TDD) and Federal Information Relay Service (FIRS) capabilities that enable individuals with hearing impairments to communicate with the Foundation about NSF programs, employment or general information. TDD may be accessed at (703) 292-5090 and (800) 281-8749, FIRS at (800) 877-8339.

The National Science Foundation Information Center may be reached at (703) 292-5111.

The National Science Foundation promotes and advances scientific progress in the United States by competitively awarding grants and cooperative agreements for research and education in the sciences, mathematics, and engineering.
To get the latest information about program deadlines, to download copies of NSF publications, and to access abstracts of awards, visit the NSF Website at https://www.nsf.gov

- **Location:** 2415 Eisenhower Avenue, Alexandria, VA 22314
- **For General Information** (NSF Information Center)**:** (703) 292-5111
- **TDD (for the hearing-impaired):** (703) 292-5090
- **To Order Publications or Forms:**

  Send an e-mail to: nsfpubs@nsf.gov

  or telephone: (703) 292-8134
- **To Locate NSF Employees:** (703) 292-5111

Privacy Act And Public Burden Statements

The information requested on proposal forms and project reports is solicited under the authority of the National Science Foundation Act of 1950, as amended. The information on proposal forms will be used in connection with the selection of qualified proposals; and project reports submitted by proposers will be used for program evaluation and reporting within the Executive Branch and to Congress. The information requested may be disclosed to qualified reviewers and staff assistants as part of the proposal review process; to proposer institutions/grantees to provide or obtain data regarding the proposal review process, award decisions, or the administration of awards; to government contractors, experts, volunteers and researchers and educators as necessary to complete assigned work; to other government agencies or other entities needing information regarding proposers or nominees as part of a joint application review process, or in order to coordinate programs or policy; and to another Federal agency, court, or party in a court or Federal administrative proceeding if the government is a party. Information about Principal Investigators may be added to the Reviewer file and used to select potential candidates to serve as peer reviewers or advisory committee members. See System of Record Notices, NSF-50, "Principal Investigator/Proposal File and Associated Records," and NSF-51, "Reviewer/Proposal File and Associated Records." Submission of the information is voluntary. Failure to provide full and complete information, however, may reduce the possibility of receiving an award.

An agency may not conduct or sponsor, and a person is not required to respond to, an information collection unless it displays a valid Office of Management and Budget (OMB) control number. The OMB control number for this collection is 3145-0058. Public reporting burden for this collection of information is estimated to average 120 hours per response, including the time for reviewing instructions. Send comments regarding the burden estimate and any other aspect of this collection of information, including suggestions for reducing this burden, to:

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