

EHR Core Research: Production Engineering Education and Research (ECR: PEER)

PROGRAM SOLICITATION

NSF 19-557



National Science Foundation

Directorate for Education & Human Resources
Division of Graduate Education
Division of Human Resource Development
Research on Learning in Formal and Informal Settings
Division of Undergraduate Education



The Boeing Company

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

May 15, 2019

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) ([NSF 19-1](#))

SUMMARY OF PROGRAM REQUIREMENTS

General Information

Program Title:

EHR Core Research (ECR): Production Engineering Education and Research (PEER)

Synopsis of Program:

The National Science Foundation (NSF) and The Boeing Company are supporting a new initiative, managed and administered by NSF through its EHR Core Research (ECR) program, to accelerate training in critical skill areas for the Nation's engineering and advanced manufacturing workforce. The *EHR Core Research: Production Engineering Education and Research* (ECR: PEER) initiative supports foundational research arising from the design, development, and deployment of creative online curricula that provide learners at various levels with skills in five focal areas: model-based systems engineering, software engineering, mechatronics, data science, and artificial intelligence. ECR: PEER invites proposals to design, develop, deploy, and study the effectiveness of online courses in any one of these focal areas using the theories and tools of the learning sciences. Proposals for these ECR: PEER *Course, Curriculum, and Evaluation* projects may request a maximum of \$2,000,000 support for a duration of up to three years.



Additionally, ECR: PEER welcomes proposals to convene experts in the academic, for-profit, and non-profit sectors to imagine the future of production engineering education for one of the five focal areas. Proposals for these ECR: PEER *Workforce Development Workshops* may request a maximum of \$100,000 support for a duration of up to one year.

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.

- Radhakishan Baheti, telephone: (703) 292-8339, email: rbaheti@nsf.gov
- John C. Cherniavsky, telephone: (703) 292-5136, email: jchernia@nsf.gov
- David L. Haury, telephone: (703) 292-8614, email: dhaury@nsf.gov
- Ann E. Rivet, telephone: (703) 292-4764, email: arivet@nsf.gov
- R. Steven Turley (lead), telephone: (703) 292-2207, email: rturley@nsf.gov
- Heather Watson, telephone: (703) 292-7091, email: hwatson@nsf.gov

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

- 47.076 --- Education and Human Resources

Award Information

Anticipated Type of Award: Standard Grant

Estimated Number of Awards: 10

NSF anticipates that there will be \$10,000,000 available for this competition. NSF expects to make up to five awards in Track 1 (*Course, Curriculum and Evaluation*) and five awards in Track 2 (*Workforce Development Workshops*).

Anticipated Funding Amount: \$10,000,000

Maximum Amount Per Award

- Track 1: \$2,000,000 for a maximum of three-years
- Track 2: \$100,000 for a maximum of one-year

Estimated program budget, number of awards and average award size/duration are subject to the quality of the proposals received and the availability of funds.

Eligibility Information

Who May Submit Proposals:

The categories of proposers eligible to submit proposals to the National Science Foundation are identified in the *NSF Proposal & Award Policies & Procedures Guide* (PAPPG), Chapter I.E.

Who May Serve as PI:

One of the goals of this solicitation is to encourage teams to use a convergent science approach (see https://www.nsf.gov/news/special_reports/big_ideas/convergent.jsp) to address challenges in education in production engineering. Proposers are encouraged to employ a convergent science approach involving the active and iterative

contributions of individuals from multiple disciplines in co-designing STEM content, educational materials, assessment and evaluation. Accordingly, senior personnel for *Course, Curriculum and Evaluation* (Track 1) proposals must collectively have expertise in:

- the specific discipline that is being taught;
- working with students at all relevant educational levels;
- learning sciences and/or cognitive sciences; and
- learning analytics or assessment.

Limit on Number of Proposals per Organization:

There are no restrictions or limits.

Limit on Number of Proposals per PI or Co-PI:

A PI or Co-PI may be identified as senior personnel in a maximum of one proposal in each track: *Course, Curriculum and Evaluation* (Track 1) projects **or** *Workforce Development Workshops* (Track 2).

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 FastLane: *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:**

Other budgetary limitations apply. Please see the full text of this solicitation for further information.

C. Due Dates

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

May 15, 2019

Proposal Review Information Criteria

Merit Review Criteria:

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

Award Administration Information

Award Conditions:

Additional award conditions apply. Please see the full text of this solicitation for further information.

Reporting Requirements:

Standard NSF reporting requirements apply.

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I. INTRODUCTION

The National Science Foundation (NSF) and The Boeing Company are supporting a new initiative, managed and administered by NSF through its EHR Core Research (ECR) program, to accelerate training in critical skill areas for the Nation's engineering and advanced manufacturing workforce. The *EHR Core Research: Production Engineering Education and Research* (ECR: PEER) initiative supports foundational research arising from the design, development, and deployment of creative online curricula that provide learners at various levels with skills in five focal areas: model-based systems engineering, software engineering, mechatronics, data science, and artificial intelligence. ECR: PEER invites proposals to design, develop, deploy, and study the effectiveness of online courses in any one of these focal areas using the theories and tools of the learning sciences.

Additionally, ECR: PEER welcomes proposals to convene experts in the academic, for-profit, and non-profit sectors to imagine the future of production engineering education for one of the five focal areas.

Recent reports have pointed out the need for innovative approaches to workforce development in the US. For example, the National Academies of Sciences, Engineering and Medicine (NASEM) noted that, "The ability of the United States to support innovation requires production and retention of individuals who are highly skilled in science, technology, engineering, and mathematics (STEM)" (see *Engineering Technology Education in the United States*¹). A second NASEM report stressed the importance of opening pathways to STEM careers for all Americans: "STEM knowledge and skills enable both individual opportunity and national competitiveness, and the nation needs to develop ways of ensuring access to high-quality education and training experiences for all students at all levels and for all workers at all career stages" (see *Developing a National STEM Workforce Strategy*²). The importance of reskilling workers was also featured in the recent Council of Economic Advisors report³ and addressed in a September 2018 workshop on reskilling America's workforce⁴.

The National Science Board (NSB) called for a national synergy to address the changing STEM workforce: "As the nature of the American workforce changes and as STEM knowledge and skills become vital to a wider range of workers, we have an opportunity to re-envision how government, educational institutions, and employers can best support the range of STEM-capable workers to meet the challenges of today and tomorrow" (see *Revisiting the STEM Workforce*⁵). As underscored by the EHR Advisory Committee, "the nature of work and the workplace are radically changing due to technological and social forces, especially in the STEM workforce" (*Strategic Re-envisioning for the Education and Human Resources Directorate*⁶); some of these same forces present new opportunities for training, skilling, and re-skilling of the STEM workforce.

¹ National Academy of Engineering. 2017. *Engineering Technology Education in the United States*. Washington, DC: The National Academies Press. <https://doi.org/10.17226/23402>.

² National Academies of Sciences, Engineering, and Medicine. 2016. *Developing a National STEM Workforce Strategy: A Workshop Summary*. Washington, DC: The National Academies Press. <https://doi.org/10.17226/21900>.

³ Council of Economic Advisors Report, Addressing America's Reskilling Challenge, <https://www.whitehouse.gov/wp-content/uploads/2018/07/Addressing-Americas-Reskilling-Challenge.pdf>.

⁴ See The Business-Higher Education Forum, Reskilling America's Workforce Workshop, <http://www.bhef.com/news-events/events/reskilling-americas-workforce-workshop>.

⁵ National Science Board. 2015. *Revisiting the STEM Workforce, A Companion to Science and Engineering Indicators 2014*, Arlington, VA: National Science Foundation (NSB-2015-10).

⁶ Strategic Re-envisioning for the education and Human Resources Directorate: A Report to the Directorate for Education and Human Resources national Science Foundation by the NSF Federal Advisory Committee for Education and Human Resources (May 1, 2014), https://www.nsf.gov/ehr/Materials/AC_ReEnvisioning_Report_Sept_2014.pdf.

II. PROGRAM DESCRIPTION

The ECR: PEER solicitation will support two related tracks of awards. It is anticipated that up to five *Course, Curriculum and Evaluation* (CCE) awards and up to five *Workforce Development Workshops* awards will be made in FY 2019, pending availability of funds.

To help align their projects with the needs of the STEM workplace, the Boeing Company intends to offer engineering and science subject matter experts (SMEs) to provide technical assistance at no cost to awardees (for any track) who choose to accept it. Acceptance of this SME offer is at the discretion of the awardee and should not be outlined or requested in the proposal.

Focal areas

Proposals should address one of the following five focal areas as it relates to production manufacturing:

- model-based systems engineering;
- software engineering;
- mechatronics;
- data science;
- artificial intelligence (AI).

In order to support the required learning science research, successful proposals will collect and utilize rich data sources, including click stream data, but also gather and analyze other data sources appropriate for the proposed research, the focal area, and the details of the learning environment. Successful proposals will also include cybersecurity, privacy, and ethical concerns as design elements.

Solicitation Tracks

NSF seeks proposals for *Course, Curriculum and Evaluation* (Track 1) projects **or** *Workforce Development Workshops* (Track 2). For this effort, NSF encourages the engagement of a range of disciplines, such as engineering, engineering education, computer science, information science, computational science, mathematics, statistics, and cognitive science.

Track 1

The purpose of the *Course, Curriculum and Evaluation* track is to revolutionize production engineering education and significantly improve the quality, quantity and diversity of the STEM workforce for production engineering in one of the above focal areas by addressing the following:

1. designing, developing, and deploying integrated online curricular materials that are vertically coherent at the: (a) professional, (b) four-year, and (c) two-year college levels;
2. aligning with industry to address workforce critical STEM skill gaps and to ground academic theories in practical work realities of production manufacturing. The Boeing Company has agreed to make science and engineering subject matter experts available to provide technical assistance for successful awardees to support alignment with the needs of workplace;
3. specifying learning objectives that are sufficiently challenging and rigorous to bring about enhanced mastery of fundamentals, sophisticated conceptual understandings, and ways of thinking essential to allow students to demonstrate success in the STEM workforce. Competitive proposals will engage learners in active learning activities and meaningful projects tied to the needs of the STEM workforce (e.g., Freeman et al., 2014⁷); lectures only and mere memorization activities are strongly discouraged;
4. drawing on the insights from Engineering Education research so that the content and context of the educational materials and activities are responsive to disciplinary concerns;
5. providing tools for those in the professional workforce to improve their current skills and acquire new skills;
6. developing critical STEM skills at the two-year college level that prepare students for the workplace and/or prepare them for an effective transition to study at the undergraduate level;
7. developing critical STEM skills at the undergraduate level that prepare students for the workplace and prepare them for an effective transition to study at the graduate level;
8. integrating the development and application of valid and reliable mechanisms to inform and assess the effectiveness of the curriculum and delivery mechanisms;
9. incorporating the principles of open science, open data, and the access principles of open educational resources (OER) for all curricular materials (including, but not limited to, digital resources such as videos, animations, images, audio files, augmented or virtual reality), learning analytics techniques and algorithms that result from funded awards;
10. modularizing the learning materials so that students can learn and obtain certification of their competency in selected areas.

Developers of new materials are required to license all work (except for computer software source code, discussed below) created with

the support of the grant under either the 3.0 Unported or 3.0 United States version of the Creative Commons Attribution (CC BY 3.0 US), Attribution-Share-Alike (CC BY-SA), or Attribution-Non-Commercial-Share-Alike (CC BY-NC-SA) license.

These licenses allow subsequent users to copy, distribute, transmit, and adapt the copyrighted work and requires such users to attribute the work in the manner specified by the grantee. Notice of the specific license used should be affixed to the work and displayed clearly when the work is made available online. For general information on these Creative Commons licenses, please visit <http://creativecommons.org/licenses/>.

It is expected that computer software source code developed or created with ECR: PEER grant funds would be released under an intellectual property license that allows others to use and build upon the work. The grantee may release all new source code developed or created with ECR: PEER grant funds under an open license acceptable to the Free Software Foundation (<http://gnu.org/licenses/>) and/or the Open Source Initiative (<http://opensource.org/licenses/>).

Strategies for Course Development and Roll Out

Where possible, the courses for **professional** audiences should be designed and deployed first. These courses should support members of the professional audience including professionals in workplace settings (i.e., currently employed in or developing skills to qualify them to excel in current or advanced positions in production engineering). The development and deployment of the courses should include the capability for gathering both usage data (navigation data and time spent with various resources) as well as psychometric data about the learners. There should be an organized plan to use these data to inform course development, assess its effectiveness, and answer research questions about the curriculum, learning system, and learners. Appropriately anonymized data should be shared in a curated public repository so that other educational researchers can use it in their work as well. The data management plan should include a provision for the data to be available for at least three years after the data are first made available. Please note NSF 19-025 "Dear Colleague Letter: STEM-Workforce Development Utilizing Flexible Personal Learning Environments" as an example of complementary research efforts NSF is encouraging that might use these data.

Courses that are vertically coherent with the professional course should be subsequently designed and deployed for four-year and two-year college students during the lifetime of the award. A set of courses are *vertically coherent* if the successful completion of the lower level courses provides the foundation for more advanced learning at the higher-level courses. Successful completion means that both content and workforce skills such as communication and collaboration addressed in the courses have been mastered. Moreover, the assessments at each level should allow the course designers to predict student performance at the next level. This will enable them to put in place appropriate supports for student learning. From a learning analytics perspective, vertical coherence demands predictive analytics not only for students completing a course at one level, but also predictive analytics for their performance at the next level. For professional level courses, it means developing predictive analytics for improved performance in the workplace.

Proposals for purely lecture online courses that do not actively engage students, and those with only pre-post assessments of student learning will not be competitive.

All proposals must explicitly address ethical and privacy issues associated with proposed data analytics and their use for the development of personalized learning systems.

Online curricular offerings developed under this solicitation should be offered by each funded educational institution for at least five years from the time the course is first deployed.

Students both inside and outside of academia who wish to obtain a certification for course or module completion or academic credit, would be expected to pay tuition or fees in accordance with the policies of the awardee institution.

Students who are not interested in the certificate or instructional support should be provided audit access to the content free of charge, in accordance with the policies of the awardee institution.

Scaling and Equipment Support

NSF seeks to ensure that the online curricular offerings and supporting materials funded by this solicitation reach the greatest number of Americans. Following the Open Educational Resources (OER) guidelines, individuals would be free to borrow, adapt and use curricular materials, including assessments, learning analytic techniques, and associated algorithms offered by an awardee organization.

Proposers may choose to adapt existing courses. However, as noted above, PIs are advised that all course materials and related resources supported under this solicitation will fall under OER guidelines.

The online courses proposed should employ the most up-to-date technologies to support STEM workforce development. However, award funds should be directed primarily towards the development and testing of the integrated series of online courses — not on the purchase of equipment. However, key technology to support a course (e.g., 3-D printers) are permitted, but should not exceed 10% of the budget.

In proposing equipment purchases, PIs should remain mindful of the goal of this solicitation to **scale** the resulting courses, nationally. Therefore, costs of equipment should not preclude reasonable adoption by under-resourced educational institutions.

Research and Evaluation

Track 1 proposals should include both an evaluation plan and a research plan as part of their project description. The evaluation plan should include a means to provide ongoing formative assessment of the materials developed as well as a summative assessment of the project's goals and objectives. The evaluation should be conducted by someone external to the project development with experience in educational evaluations.

The research plan must include the following elements:

1. Clearly articulated research questions that build on existing literature and align with the proposed project objectives;
2. A description of the research subjects and a plan for their recruitment to the study;
3. Data collection methods including instruments, surveys, and/or data logs;

4. Details regarding the data analysis approach, including how the researchers will address issues of validity and reliability;
5. A clear plan for dissemination of the research findings to a variety of audiences and stakeholders.

The joint U.S. Department of Education Institute of Education Sciences and NSF [Common Guidelines for Education Research and Development](#) offers guidance on building the evidence base in STEM learning. Research and development efforts that increase understanding of effective undergraduate STEM teaching and learning provide the foundation for building the STEM workforce of tomorrow and improving scientific literacy.

Track 2

To support the education of the future STEM workforce in production engineering, NSF challenges interdisciplinary science, engineering and education teams to produce plans for developing a national infrastructure to support US STEM workforce development. This infrastructure includes forward-looking, highly adaptable, distributed learning environments that can personalize learning for individual, diverse learners in collaborative settings applied to the intersection of production manufacturing and one of the above focal areas.

The purpose of the *Workforce Development Workshops* track of the program is to solicit and synthesize insights from experts in the academic, for-profit, and non-profit sectors to describe the future of production engineering and production engineering education for one of the focal areas. The Boeing Company has agreed to make science and engineering subject matter experts available to provide technical assistance for successful awardees to support alignment of this vision with the needs of workplace.

NSF encourages the engagement of people from a range of disciplines, such as engineering, computer science, information science, computational science, mathematics, statistics, education research, and cognitive science. This engagement may include experts in topics such as human-computer interaction; data streaming, assimilation, visualization, analytics, machine learning, deep learning, multi-modal analytics, social network analyses, and adaptive rapid experimental design. While NSF primarily funds domestic institutions, expert advisors may come from academia, industry, or non-profits, both within the US and internationally. (Please note Chapter I.E. in the [PAPPG](#) for information about funding international consultants.)

The workshop's findings should include recommendations for improving the quality, quantity and diversity of the STEM workforce for the identified focal area. Topic areas to explore may include:

- How should future STEM workforce development learning environments draw on and exploit pervasive data from sensors, cyber-physical systems, and from the internet of things?
- What innovative approaches to research methods, statistical techniques and modeling formalisms are necessary to capture, characterize and support causal claims about individual or team-based STEM workforce development around production engineering?
- How can advances from data science inform innovative formative, continuous, or summative assessments that provide rich diagnostic information on STEM workforce learning?
- How can future STEM learning environments capitalize on mentor, teacher or learner "presence" via virtual or immersive technologies engaging tools such as augmented or virtual reality?

Workshop Design

- Workshops may be held in any suitable location in the U.S.
- Workshops should be open (i.e., not by invitation only). Proposers should make provision for in-person convenings with an option for virtual participation.
- Meaningful involvement of graduate student(s) and/or postdoctoral researcher(s) in all projects is strongly encouraged.
- Each workshop proposal should budget support for its personnel, including organizing committee members, its workshop meetings and activities, and its travel costs for selected project personnel to attend.
- All PIs must propose a creative dissemination plan that goes beyond publishing research papers and presenting at research conferences, i.e., a plan that is likely to impact a range of audiences.
- Workshop PIs should collaborate with relevant research coordination hubs to disseminate the findings from the Track 1 projects.
- In addition to standard reporting expectations, each conference project should post a white paper on a public project website that describes the participants and insights from the workshop and share this white paper with NSF staff.

References

1. National Science Foundation (2013). *Common Guidelines for Education Research and Development (NSF 13-126)*. A Report from the Institute of Education Sciences, U.S. Department of Education and the National Science Foundation. https://www.nsf.gov/publications/pub_summ.jsp?ods_key=nsf13126
2. Planning Committee for the National Summit on Developing a STEM Workforce Strategy, Board on Higher Education and Workforce, Policy and Global Affairs, National Academies of Sciences, Engineering, and Medicine, Joe Alper (Rapporteur). (2016). *Developing a National STEM Workforce Strategy: A Workshop Summary*, National Academies Press.
3. Kober, N., (2015). *Reaching Students: What Research Says About Effective Instruction in Undergraduate Science and Engineering*. Board on Science Education, Division of Behavioral and Social Sciences and Education, Washington, D.C.: The National Academies Press. http://www.nap.edu/catalog.php?record_id=18687
4. The Coalition for Reform of Undergraduate STEM Education, Catherine L. Fry (Editor). (2014). *Achieving Systematic Change: A Source Book for Advancing and Funding Undergraduate STEM Education*. Washington, D. C.: The Association of American Colleges and Universities. <http://www.aacu.org/pkal/sourcebook>
5. Booth, W.C, Colomb, G. C., and Williams, J. M. (2003). *The Craft of Research*, 2nd edition. Chapter 4, Section 4.1.1, The University of Chicago Press.
6. Intelligent Cognitive Assistants (ICA) Workshop Summary and Research Needs: Collaborative Machines to Enhance Human Capabilities. Report on a February 7, 2018 workshop. https://www.nsf.gov/crssprgm/nano/reports/ICA2_Workshop_Report_2018.pdf

⁷ Freeman, Eddy, McDonough, Smith, et al. (2014). Active learning increases student performance in science, engineering, and

III. AWARD INFORMATION

Estimated program budget, number of awards and average award size/duration are subject to the quality of the proposals received and the availability of funds.

IV. ELIGIBILITY INFORMATION

Who May Submit Proposals:

The categories of proposers eligible to submit proposals to the National Science Foundation are identified in the *NSF Proposal & Award Policies & Procedures Guide* (PAPPG), Chapter I.E.

Who May Serve as PI:

One of the goals of this solicitation is to encourage teams to use a convergent science approach (see https://www.nsf.gov/news/special_reports/big_ideas/convergent.jsp) to address challenges in education in production engineering. Proposers are encouraged to employ a convergent science approach involving the active and iterative contributions of individuals from multiple disciplines in co-designing STEM content, educational materials, assessment and evaluation. Accordingly, senior personnel for *Course, Curriculum and Evaluation* (Track 1) proposals must collectively have expertise in:

- the specific discipline that is being taught;
- working with students at all relevant educational levels;
- learning sciences and/or cognitive sciences; and
- learning analytics or assessment.

Limit on Number of Proposals per Organization:

There are no restrictions or limits.

Limit on Number of Proposals per PI or Co-PI:

A PI or Co-PI may be identified as senior personnel in a maximum of one proposal in each track: *Course, Curriculum and Evaluation* (Track 1) projects **or** *Workforce Development Workshops* (Track 2).

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 Grants.gov or via the NSF FastLane system.

- Full proposals submitted via FastLane: Proposals submitted in response to this program solicitation should be prepared and submitted in accordance with the general guidelines contained in the *NSF Proposal & Award Policies & 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) 292-7827 or by e-mail from nsfpubs@nsf.gov. Proposers are reminded to identify this program solicitation number in the program solicitation block on the NSF Cover Sheet For Proposal to the National Science Foundation. Compliance with this requirement is critical to determining the relevant proposal processing guidelines. Failure to submit this information may delay processing.
- 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) 292-7827 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 the NSF FastLane system. PAPPG Chapter II.D.3 provides additional information on collaborative proposals.

See PAPPG Chapter II.C.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.

Track 2 Proposals

Proposals should be prepared and submitted in accordance with the guidance for Conference proposals contained in Section II.E.7 of the *NSF Proposal & Award Policies & Procedures Guide (PAPPG) (NSF 19-1)*. Proposal titles should begin with the phrase, "ECR: PEER:" The "Conference" type of proposal should be selected in the proposal preparation module in FastLane and proposals should be directed to the EHR Core Research (ECR) Program.

B. Budgetary Information

Cost Sharing:

Inclusion of voluntary committed cost sharing is prohibited.

Other Budgetary Limitations:

For all strands, the level of funding for the proposal should align with the maturity of the proposed work, the size and scope of the scientific effort, as well as the capacity of the interdisciplinary team to conduct the proposed research.

Track 1

Course, Curriculum and Evaluation projects can be funded up to \$2,000,000 with a duration of up to three years.

Track 2

Workforce Development Workshops can be funded up to \$100,000 with a duration up to one year.

C. Due Dates

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

May 15, 2019

D. FastLane/Grants.gov Requirements

For Proposals Submitted Via FastLane:

To prepare and submit a proposal via FastLane, see detailed technical instructions available at: <https://www.fastlane.nsf.gov/a1/newstan.htm>. For FastLane user support, call the FastLane Help Desk at 1-800-673-6188 or e-mail fastlane@nsf.gov. The FastLane Help Desk answers general technical questions related to the use of the FastLane 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: <http://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 the NSF FastLane system for further processing.

Proposers that submitted via FastLane are strongly encouraged to use FastLane 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 *Building the Future: Investing in Discovery and Innovation - NSF Strategic Plan for Fiscal Years (FY) 2018 – 2022*. 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.C.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.C.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 underrepresented minorities 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 Plan and the Postdoctoral Researcher Mentoring Plan, as appropriate.

Additional Solicitation Specific Review Criteria

In addition to the Intellectual Merit and Broader Impact criteria, for proposals in Track 1: *Course, Curriculum and Evaluation*, reviewers will be asked to evaluate:

- the applicability of course curricula to current (and anticipated) production engineering needs in the workforce, and the involvement of industrial partners and/or advisors to inform curricular content and course deployment;
- plans to enable learners to certify competence in individual course outcomes;
- the potential to use proposed course materials at multiple educational levels;
- the quality of the delivery mechanism;
- plans for making research data, course materials, and analysis tools publicly available; and
- plans for sustaining course availability beyond the period of funding.

For Track 2: *Workforce Development Workshops*, in addition to the Intellectual Merit and Broader impact criteria, reviews will be asked to evaluate:

- the plan for coordinating research insights from various Track 1 projects and related research efforts that complement those in this solicitation;
- the plan for coordinating workshop activities through relevant research hubs or other appropriate integration networks; and
- the inclusion of industrial workforce organizations and members.

Proposers are advised that representatives from Boeing may attend the review panel as observers.

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 applicants whether their proposals have been declined or recommended for funding within six months. Large or particularly complex proposals or proposals from new awardees 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 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 a Grants Officer in the Division of Grants and Agreements. 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. Paper copies may be obtained from the NSF Publications Clearinghouse, telephone (703) 292-7827 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=papppg.

Special Award Conditions:

Standard NSF award conditions apply. Additionally, grantees on awards made under this solicitation shall use the following acknowledgement language in any publications associated with the award:

"This material is based upon work supported by the National Science Foundation under award No. _____ (NSF award number) and is supported in part by a gift to the National Science Foundation from The Boeing Company."

Developers of new materials are required to license all work (except for computer software source code, discussed below) created with the support of the grant under either the 3.0 Unported or 3.0 United States version of the Creative Commons Attribution (CC BY), Attribution-ShareAlike (CC BY-SA), or Attribution-NonCommercial-ShareAlike (CC BY-NC-SA) license.

These licenses allow subsequent users to copy, distribute, transmit, and adapt the copyrighted work and requires such users to attribute the work in the manner specified by the grantee. Notice of the specific license used would be affixed to the work and displayed clearly when the work is made available online. For general information on these Creative Commons licenses, please visit <http://creativecommons.org/licenses/>.

It is expected that computer software source code developed or created with ECR: PEER grant funds be released under an intellectual property license that allows others to use and build upon the work. The grantee may release all new source code developed or created with IUSE grant funds under an open license acceptable to the Free Software Foundation (<http://gnu.org/licenses/>) and/or the Open Source Initiative (<http://opensource.org/licenses/>).

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 project report, and a project outcomes report for the general public.

Failure to provide the required annual or final 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 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:

- Radhakishan Baheti, telephone: (703) 292-8339, email: rbaheti@nsf.gov
- John C. Cherniavsky, telephone: (703) 292-5136, email: jchernia@nsf.gov
- David L. Haury, telephone: (703) 292-8614, email: dhaury@nsf.gov
- Ann E. Rivet, telephone: (703) 292-4764, email: arivet@nsf.gov
- R. Steven Turley (lead), telephone: (703) 292-2207, email: rturley@nsf.gov
- Heather Watson, telephone: (703) 292-7091, email: hwatson@nsf.gov

For questions related to the use of FastLane, contact:

- FastLane Help Desk, telephone: 1-800-673-6188; e-mail: fastlane@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 <http://www.grants.gov>.

Related Programs:

- Improving Undergraduate STEM Education (IUSE)
- STEM + Computing Partnerships (STEM + C)
- Historically Black Colleges and Universities Undergraduate Program (HBCU-UP)
- Tribal Colleges and Universities Program (TCUP)
- Advanced Technical Education (ATE)
- Discovery Research PreK-12 program (DRK-12)

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 (FASSED) 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.E.6 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) 292-7827
- **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 awardees 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 applicants 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 Systems of Records, *NSF-50*, "Principal Investigator/Proposal File and Associated Records," 69 Federal Register 26410 (May 12, 2004), and *NSF-51*, "Reviewer/Proposal File and Associated Records," 69 Federal Register 26410 (May 12, 2004). 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:

Suzanne H. Plimpton
Reports Clearance Officer
Office of the General Counsel
National Science Foundation
Alexandria, VA 22314

X. APPENDIX

Resources

- Committee on STEM Education, National Science and Technology Council. (2018). *Charting a Course for Success: America's Strategy for STEM Education*. A report by the Committee on STEM Education of the National Science & Technology Council. Retrieved January 2019 from <https://www.whitehouse.gov/wp-content/uploads/2018/12/STEM-Education-Strategic-Plan-2018.pdf>
- Council of Economic Advisors. (2018). *Addressing America's Reskilling Challenge*. Retrieved January 2019 from <https://www.whitehouse.gov/wp-content/uploads/2018/07/Addressing-Americas-Reskilling-Challenge.pdf>
- *Intelligent Cognitive Assistants (ICA): Workshop Summary and Research Needs—Collaborative Machines to Enhance Human Capabilities*. Report of a workshop held November 2017. Retrieved January 2019 from https://www.nsf.gov/crssprgm/nano/reports/ICA2_Workshop_Report_2018.pdf
- National Science Board. (2010). *Preparing the Next Generation of STEM Innovators: Identifying and Developing our Nation's Human Capital (NSB-10-33)*. Retrieved January 2019 from https://www.nsf.gov/publications/pub_summ.jsp?ods_key=nsb1033.
- National Science Foundation. Convergence Research at NSF. Retrieved January 2019 from <https://www.nsf.gov/od/oia/convergence/index.jsp>.
- National Science Foundation. *Dear Colleague Letter: Principles for the Design of Digital Science, Technology, Engineering, and Mathematics (STEM) Learning Environments (NSF 18-017)*. Retrieved January 2019 from https://www.nsf.gov/publications/pub_summ.jsp?ods_key=nsf18017.
- National Science Foundation. NSF's 10 Big Ideas: Future of Work at the Human Technology Frontier. Retrieved January 2019 from https://www.nsf.gov/news/special_reports/big_ideas/human_tech.jsp.
- President's Council of Advisors in Science and Technology (PCAST). (2014). *Accelerating U.S. Advanced Manufacturing*. Report to the President. Retrieved January 2019 from https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/PCAST/amp20_report_final.pdf.

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National Science Foundation, 2415 Eisenhower Avenue, Alexandria, Virginia 22314, USA
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