

Article

The Future of Worker Enhancement

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Abstract: Announced in 2016 and concluded in 2023, the Future of Work at the Human-Technology Frontier was one of the 10 Big Idea initiatives of the National Science Foundation, built on convergence of many fields of engineering and also some social and cognitive science that served primarily a supportive rather than critical role. Drawing upon extensive data from the NSF online grant abstracts system, this article considers how the United States seeks to enhance the productivity of workers, but possibly limited to abilities that enhance national economic and military competitiveness in an unstable world, rather than improving worker prosperity and social well-being. Some research exploring the wider implications of artificial intelligence and related technologies did emerge, so it receives emphasis. The data required for this study were entirely public, and further research focused on particular topics can be conducted by downloading new and expanded data from the NSF website.

Keywords: labor; productivity; artificial intelligence; National Science Foundation

1. An Initiative at the National Science Foundation

The future of humanity depends very much upon competent but also inspirational leadership within science and engineering (Bainbridge 2012). In 2016, at a time when automation and globalization were threatening employment by American workers, the National Science Foundation, then led by astrophysicist France Córdova, planned to “bring together NSF research communities to conduct basic scientific research on the interaction of humans, society, and technology that will help shape the future of work to increase opportunities for workers and productivity for the American economy.”¹ The May 2021 NSF budget request stressed the need for convergence among fields of expertise because many “research challenges are inspired by deep scientific questions or pressing societal needs and require the integration of multi-disciplinary perspectives.”² Already in 2017, four of NSF’s seven directorates had collaborated to explore Future of Work at the Human-Technology Frontier (FW-HTF), and in 2022 a new application-oriented directorate was created, Technology, Innovation and Partnerships, that immediately joined them (Guston 2023).

Yet questions can be raised, such as whether American productivity will increase through enhancement of workers versus their exploitation. Indeed, much of the research concerns education to improve the capability of workers, or innovative technologies like artificial intelligence that would magnify worker abilities during labor. Extreme critics may suggest that rigorous training of workers is indoctrination, and partnership with artificial intelligence is slavery. Conceivably, if workers are trained to partner with artificial intelligences at work, they may themselves act like machines at home. More reasonably, we may ask whether enough scientific effort is being invested in the future of work that is not dependent upon advanced technologies, or that explores the best ways to ensure that high tech applications serve humanity. Perhaps careful research can assess exactly which forms of human enhancement are actually beneficial.

The Future of Work initiative was included in 10 Big Ideas that sought to energize discovery and invention at the National Science Foundation. The journal *Science* reported

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that the outgoing chair of NSF's governing Science Board, Dan Arvizu, proclaimed: "It's an intellectual exercise unparalleled in government, and demonstrates the value of NSF to the nation" (Mervis 2016). Three years later a visitor to the NSF website could learn: "Since 2017, NSF has been building a foundation for the Big Ideas through pioneering research and pilot activities. In 2019, NSF will invest \$30 million in each Big Idea and continue to identify and support emerging opportunities for U.S. leadership in Big Ideas that serve the Nation's future."³ Table 1 offers a perspective from the end of the initiative, based on data from NSF's annual funding requests to Congress.⁴

Table 1: Official NSF Fiscal Year Big Idea Investments in Millions of Dollars

	Actual Funding				Request	
	2018	2019	2020	2021	2022	2023
Research Big Ideas:						
The Future of Work (FW-HTF)		49.56	30.00	172.89	30.00	175.80
Harnessing the Data Revolution (HDR)		51.46	30.00	191.79	30.00	182.11
Understanding the Rules of Life (URoL)		30.00	29.95	113.92	30.00	93.50
Navigating the New Arctic (NNA)		30.00	27.20	40.11	30.00	35.20
Windows on the Universe (WoU)		30.00	30.00	74.80	30.00	61.85
The Quantum Leap (QL)		30.02	30.00			
Enabling Big Ideas:						
Growing Convergence Research (GCR)	5.00	15.80	15.90	15.99	24.17	16.00
Mid-scale Research Infrastructure		60.04	30.37	106.49	126.25	126.25
NSF INCLUDES (broaden participation)	19.95	20.20	20.75	20.75	46.50	50.50
NSF 2026 (new ideas from public)		6.51	6.42			

NSF budget requests include tables that tend to report how much was actually spent two years earlier on a particular funding line, for comparison with the request for the coming fiscal year, but the request for FY2024 did not include 10 Big Ideas any more, so the last two years of these data are limited to the requests. The dollar amounts are represented in Table 1 following the Congressional style, and 30.00 means \$30,000,000. Six of the ten ideas promoted research directly, both by funding some very innovative research and by supporting development of the community of researchers, while the four other ideas were considered enablers of progress.

Years before Córdoba assembled the Big Ideas, the Growing Convergence Research enabler had already been presented in NSF reports that emphasized human enhancement (Roco and Bainbridge 2002; Roco and Montemagno 2004; Bainbridge and Roco 2006a, 2006b, 2016; Roco et al. 2013; Chowdhury, Bainbridge and Kronz 2023). In 2019, two of the computing-related Big Ideas got extra support from Convergence Accelerator Grants: 19.60 million for Future of Work at the Human-Technology Frontier, and 21.45 million for Harnessing the Data Revolution.⁵ Mid-scale Research Infrastructure added to existing NSF support for physical research tools of lower cost than really big observatories. NSF INCLUDES stands for "Inclusion across the Nation of Communities of Learners of Underrepresented Discoverers in Engineering and Science." It intended to reduce gender or minority inequality by recruiting scientists and engineers from underrepresented groups. NSF 2026 used an online Idea Machine to gather nearly 800 suggestions from the general public about future NSF initiative topics.⁶

The first Convergence Accelerator competition had three parts, Track A1 for Harnessing the Data Revolution, and the others for Future of Work: (B1) AI and Future Jobs, and (B2) National Talent Ecosystem. These were Research Advanced by Interdisciplinary Science and Engineering (RAISE) grants that do not require external peer review, with the goal "to support bold, interdisciplinary projects... Scientific advances lie in great part outside

the scope of a single program or discipline, such that substantial funding support from more than one program or discipline is necessary.”⁷

The accelerator concept involves a dynamic funding plan in which the Phase I awards were all one-year standard grants just under \$1,000,000 each, after which the research teams would compete against each other through peer review for further funding in Phase II that could reach an additional \$5,000,000. Table 2 lists the 9 of the 43 Phase I teams that received Phase II support, “to include leveraging innovation processes and integrating multidisciplinary research and cross-cutting partnerships to develop solution prototypes and to build a sustainability model to continue impact beyond NSF support.”⁸

Table 2: The Initial Set of Two-Stage Convergence Grants

Award ID	2019 Title	2020 Title	Organization
1937160 2033569	A Multi-Scale Open Knowledge Network for Precision Medicine	A1: A Multi-Scale Open Knowledge Network for Biomedicine	U California, San Francisco
1936940 2033558 2132318	Simultaneous Knowledge Network Programming and Extraction	A1: Knowledge Network Development Infrastructure with Application to COVID-19 Science and Economics	U Michigan, Ann Arbor / MIT
1936677 2033521	Spatially-Explicit Models, Methods, and Services for Open Knowledge Networks	A1: KnowWhereGraph: Enriching and Linking Cross-Domain Knowledge Graphs using Spatially-Explicit AI Technologies	U California, Santa Barbara
1937123 2033604	Northwestern Open Access to Court Records Initiative	A1: Systematic Content Analysis of Litigation Events (SCALES) Open Knowledge Network to Enable Transparency and Access to Court Records	Northwestern U
1937099 2033607	The Urban Flooding Open Knowledge Network	A1: The Urban Flooding Open Knowledge Network (UF-OKN)	U Cincinnati
1937036 2033615	Skill-LeARn: Affordable Augmented Reality Platform for Scaling Up Manufacturing Workforce, Skilling	B1: Skill-XR: An Affordable and Scalable X-Reality (XR) Platform for Skills Training and Analytics in Manufacturing Workforce Education	Purdue U
1937068 2033578	Competency Catalyst	B1: Competency Catalyst Phase II	Georgia Tech / Eduworks Corp
1936970 2033413	Empowering Neurodiverse Populations for Employment through Inclusion AI and Innovation Science	B1: Inclusion AI for Neurodiverse Employment	Vanderbilt U
1937053 2033592	Learning Environments with Advanced Robotics for Next-Generation Emergency Responders (LEARNER)	B2: Learning Environments with Augmentation and Robotics for Next-gen Emergency Responders (LEARNER)	Virginia Polytechnic Institute / Texas A&M

The first column gives the ID numbers of the awards that allow access to their abstracts on the NSF website, which may also require checking the Expired Awards box on the search page.⁹ The instructions to principal investigators emphasized convergence of multiple

areas of expertise: “The submitted project team must represent a mix of disciplines, expertise and organizations from academia, industry, nonprofits, government, and other communities of practice and sectors.”¹⁰ In three cases, the host institution changed, one of them dividing Phase II across two parts, but with significant continuity of the research teams. The nine Phase II awards were not “grants” but “cooperative agreements,” a form of funding that gives NSF more direct management responsibilities. The four projects related to Future of Work, at the bottom of Table 2, seemed directly related to human enhancement through skill training and partnership with artificial intelligence. The five Data Revolution projects seem functionally similar, providing people with information so they can do their work better.

2. Convergence at the Human-Technology Frontier

We might have imagined that the Future of Work big idea would focus on social issues like income inequality and the impact of globalization on the American manufacturing industries that might best be handled through policy changes, such as increased taxation on imported goods combined with increased wages for workers. Studies using several datasets had indicated that, adjusted for inflation, workers’ wages have fallen significantly behind productivity progress over the past half-century, even in significant areas failing to increase at all recently (Kehrig and Vincent 2018; Kochan and Kimball 2019; Groshen and Holzer 2019). The four research themes of FW-HTF included one that might address that problem, “illuminating the socio-technological landscape,” but frankly that phrase is vague, and might or might not include studies of social class and worker exploitation. The three other themes seemed obviously related to increasing worker productivity: “building the human-technology partnership, augmenting human performance, fostering lifelong learning.”¹¹ Yet we may reasonably have doubts whether lifelong learning can really allow elderly workers to compete with young ones who are already trained to work in emerging areas, not to mention how to support education of workers who suddenly became unemployed as an obsolete industry declined.

The activity charting the Future of Work evolved logically, beginning with involvement by one division in each of four NSF directorates, and then growing. Table 3 shows the investments through fiscal year 2023, from abstracts linked to this Big Idea’s main web page.¹² These are all standard grants, so even the most recent years are good estimates of the total investment, although small supplements might be added later to some grants that were still active after the end of fiscal year 2023. Also, there were fully 22 cases in which a grant was transferred to a new institution where the principal investigator had moved, which often falsely duplicated funding data because a new abstract was posted, so those cases were examined closely and the probable total funding was applied to the date range of the original grant. As in Table 2, the primary source of data was an official list of grant abstracts that could be downloaded from a page of the NSF website devoted to the Future of Work.¹³ Each abstract applies at least one *element code* that defines the budget line from which the investment came, which was 082Y for 2018 FW-HTF grants and 103Y for the “core” grants, often including but not specifying dollars from other programs. Also there were one or more *reference codes* that describe the conceptual area, which is 063Z for Future of Work, and that code was applied by other programs to many grants that did not have funding explicitly allocated to the Big Idea.

The first year in Table 3 was exploratory and organizational, funding seven workshops to discuss future directions and two Research Coordination Networks (RCNs) “supporting groups of investigators to communicate and coordinate their research.”¹⁴ The 2018 grants were devoted to Advancing Cognitive and Physical Capabilities, which an NSF news article described thus: “The National Science Foundation (NSF) is investing over \$25 million in 26 projects to advance the cognitive and physical capabilities of

workers in the context of human-technology interactions. These new awards will address critical social, technical, educational and economic needs in the workplace.”¹⁵ After two years of preparations, the “core” competition followed this vision, quoting from its last grant proposal solicitation: “to support multi-disciplinary research to sustain economic competitiveness, to promote worker well-being, lifelong and pervasive learning, and quality of life, and to illuminate the emerging social and economic context and drivers of innovations that are shaping the future of jobs and work.”¹⁶

Table 3: Work at the Human-Technology Frontier Grants

Directorate and Division		Explore 2017	Capabilities 2018	Core 2019-2023	Only 063Z Reference	Total
CISE	Information and Intelligent Systems	\$643,124	\$4,499,985	\$27,749,582	\$36,435,246	\$84,781,938
	Computer and Network Systems	\$0	\$2,016,743	\$10,763,582	\$2,673,676	
ENG	Civil, Mechanical and Manufacturing Innovation	\$564,924	\$14,053,169	\$40,658,288	\$8,598,393	\$70,626,391
	Electrical, Communications and Cyber Systems	\$0	\$0	\$5,502,570	\$0	
	Emerging Frontiers and Multidisciplinary Activities	\$0	\$0	\$499,047	\$0	
	Engineering Education and Centers	\$0	\$0	\$0	\$750,000	
EDU	Undergraduate Ed.	\$199,185	\$4,012,804	\$17,339,368	\$0	\$55,517,956
	Research on Learning	\$0	\$1,478,882	\$9,857,435	\$299,661	
	Human Resource Development	\$0	\$0	\$1,949,952	\$0	
	Graduate Education	\$0	\$0	\$0	\$20,380,669	
SBE	Behavioral and Cognitive Sciences	\$217,738	\$0	\$1,890,970	\$5,814,583	\$51,043,520
	Social and Economic Sciences	\$0	\$3,128,902	\$29,142,441	\$7,941,565	
	Multidisciplinary Activities	\$0	\$1,613,455	\$0	\$1,293,866	
MPS	Materials Research	\$0	\$0	\$0	\$40,884,502	\$40,884,502
OD	Integrative Activities	\$0	\$0	\$4,446,295	\$0	\$5,988,427
	International Science and Engineering	\$0	\$0	\$0	\$1,542,132	
TIP	Innovation and Technology Ecosystems	\$0	\$0	\$1,999,957	\$0	\$1,999,957

The first directorate in the table, arranged by total funding investment, is Computer and Information Science and Engineering (CISE), while the second is Engineering (ENG). The Materials Research division in the Mathematical and Physical Sciences (MPS) directorate has aspects of engineering, as its scope covers “the broad intersection of many disciplines with materials science & engineering,”¹⁷ but it was not officially involved in this Big Idea, and merely included the 063Z reference code in two regular 2019 research projects and three major 2020 “science and engineering centers” that also carried several other reference codes. While also supporting small planning grants, the Office of Integrative Activities in the Office of the Director (OD) chiefly funded research based on physical application of artificial external supporting structures to workers: “In multiple industrial sectors including manufacturing and construction, industrial exoskeleton technologies have substantial potential to improve productivity, and worker safety and well-being; and to equalize job opportunity by allowing diverse populations to enter and stay employed in physically demanding jobs that are otherwise inaccessible.”¹⁸

The third directorate in the table clearly had the important responsibility to develop the best teaching methods for students, not only in computer science departments but also others that related to the Big Idea’s themes. Yet during these years it was undergoing a significant change in its public presentation, giving greater emphasis to engineering broadly defined. The Directorate for Education and Human Resources (EHR) became the Directorate for STEM Education (EDU), and its Division of Human Resource Development became the Division of Equity for Excellence in STEM.¹⁹ Prior to its name change, in text carried over to its updated web page, the division already declared its “mission is to grow the innovative and competitive U.S. science, technology, engineering and mathematics (STEM) workforce that is vital for sustaining and advancing the Nation’s prosperity by supporting the broader participation and success of individuals currently underrepresented in STEM and the institutions that serve them.”²⁰ A 2012 report from the Congressional Research Service demonstrated the political significance of the concept: “Federal policymakers have an active and enduring interest in STEM education and the topic is frequently raised in federal science, education, workforce, national security, and immigration policy debates” (Gonzalez and Kuenzi 2012: 1-2). It also noted that unlike other agencies, NSF often included social science in its definition of STEM. However, NSF has always been under political pressure to constrain or even avoid the social sciences (England 1983; Larsen 1992; Solovey 2020).

The 10 Big Ideas initiative came at a time when the world at large, as well as NSF within it, placed a great emphasis on societal transformations energized by computer and communications technologies, for better, frankly, or worse. Harnessing the Data Revolution (HDR) promoted “fundamental research in data science and engineering, the development of a cohesive, federated, national-scale approach to research data infrastructure, and the development of a 21st-century data-capable workforce.”²¹ With a dramatic, even mystical name, The Quantum Leap (QL) had radical goals that emphasized information technology: “Exploiting quantum mechanics to observe, manipulate, and control the behavior of particles and energy at atomic and subatomic scales, resulting in next-generation technologies for sensing, computing, modeling, and communicating.”²² An initiative that was not labeled a Big Idea, but could have been, is the hugely expensive set of Artificial Intelligence Institutes managed by CISE, that from November 2021 through January 2024 had cost \$248,632,558.²³

On October 30, 2023, the President of the United States had issued an Executive Order on the Safe, Secure, and Trustworthy Development and Use of Artificial Intelligence, which required NSF to give greater attention to potential negative broader impacts going forward:

Artificial intelligence (AI) holds extraordinary potential for both promise and peril. Responsible AI use has the potential to help solve urgent challenges while making our world more prosperous, productive, innovative, and secure. At the same time,

irresponsible use could exacerbate societal harms such as fraud, discrimination, bias, and disinformation; displace and disempower workers; stifle competition; and pose risks to national security. Harnessing AI for good and realizing its myriad benefits requires mitigating its substantial risks. This endeavor demands a society-wide effort that includes government, the private sector, academia, and civil society.²⁴

The leader of NSF at that point in time was no longer France A. Córdova, because the Director position is temporary and limited to six years. She had been replaced in 2020 by Sethuraman Panchanathan, a computer scientist who often expressed great enthusiasm about the future of his field, but may not have favored critical assessment of its substantial risks. On January 24, 2024, he announced the response to the Executive Order Democratizing the future of AI R&D, which was described as the National AI Research Resource pilot: "By investing in AI research through the NAIRR pilot, the United States unleashes discovery and impact and bolsters its global competitiveness. To continue leading in AI research and development, we must create opportunities across the country to advance AI innovation and strengthen educational opportunities, empowering the nation to shape international standards and igniting economic growth."²⁵ Perhaps *democratizing* will later bring in serious consideration of social issues, but that does not seem to have happened yet.

To be sure, the NSF research proposal review process considers ethical issues that relate to the particular research methodology, such as privacy and other rights of human research subjects.²⁶ Also, the educational programs often include ethical principles among what must be taught to students.²⁷ But research on harmful social impacts of AI innovations is rather rare and tends not to examine closely the extent to which corporations, government agencies, or other actors are using the technology unethically. Of course, the research priorities are largely set for NSF by Congress and the President of the United States, in its annual funding and other government decisions, so we cannot lay the blame at the door of the National Science Foundation.

3. Perspectives via Large Language Models

Recent research has explored a variety of applications for *chatbots*, artificial intelligence systems that communicate with the user via written text based on using large language models to derive meaningful sentences from a huge information database and any text files the user has uploaded into the system. Here the popular AI tool ChatGPT-4 will be used simply to summarize grant abstracts from the Future of Work at the Human-Technology Frontier, thus exploring along that exact frontier. My access to an advanced chatbot system was provided through the Lifonaut Project of the non-profit Terasem Movement Foundation.²⁸ The text files uploaded into the chatbot were the descriptions in abstracts of Future of Work core grants from the four cooperating directorates of NSF, kept separate for comparison.

Computer and Information Science and Engineering (CISE) supported core 2019-2023 FW-HTF grants that had 50 different abstracts, and their text totaled 22,139 words. The 56 Engineering (ENG) abstracts totaled 25,305 words, while STEM Education (EDU) added 24 abstracts with 11,442 words, and Directorate for Social, Behavioral and Economic Sciences (SBE) completed the dataset with 35 abstracts and 13,083 words. Running them separately through ChatGPT-4, I asked the bot to predict the future of work at the human-technology frontier, and here are the four rather detailed responses from the directorates:

CISE: The future of work at the human-technology frontier is poised to be a fascinating blend of collaboration and innovation. As we delve deeper into this evolving landscape, one key area of focus is the integration of human-robot collaboration, particularly in sectors like industrialized construction. By developing

advanced systems and frameworks, we can enable robots to work alongside human workers efficiently and safely, enhancing the overall workflow and preserving the human touch in craftwork. Moreover, the introduction of technologies such as exoskeletons could significantly impact work organization, necessitating changes in task allocation, job roles, and training programs. This integration will require a thoughtful approach to ensure that workers are well-equipped to adapt to these new tools and processes. In the realm of gig work, there is a need to further investigate and understand these arrangements, as they represent a significant shift in how work is structured. By developing new data sources and research plans, we can gain deeper insights into gig work, ultimately improving the work experience for short-term workers through social learning and technology integration. Overall, the future of work will likely be characterized by a harmonious blend of human ingenuity and technological advancement, leading to enhanced productivity, job satisfaction, and well-being for workers across various industries.

ENG: The future of work at the human-technology frontier is poised to be transformative, with a strong emphasis on collaboration between humans and robots. By developing multidisciplinary research teams, we can tackle complex challenges and create innovative solutions that enhance productivity and working conditions. This partnership will likely streamline processes, automate routine tasks, and enable faster decision-making, ultimately leading to improved infrastructure management and service delivery. As we explore new ways for humans and robots to work together, we can expect advancements in collaborative technologies that redefine roles and responsibilities, setting new standards for efficiency and effectiveness across various industries.

EDU: The future of work at the human-technology frontier is likely to be characterized by a seamless collaboration between humans and advanced technologies, leading to enhanced work outcomes and skill development. As we explore potential interactions in crowd work settings, we anticipate that automated, individualized feedback will play a significant role in professional learning, allowing workers to acquire new skills and improve their performance. In manufacturing and other professional domains, understanding the human-technology partnership will be crucial. By studying human behavior and cognitive processes, we can develop tailored solutions to optimize worker performance and reduce cognitive strain. This will ensure that workers are equipped to transition to high-skilled digital jobs, fostering a more efficient and innovative work environment. The integration of AI and new human-computer interaction paradigms will likely streamline tasks and enhance communication, making work more intuitive and collaborative. As we continue to advance knowledge in fields like crowdsourcing, AI, and cognitive science, we can expect more equitable and sustainable work environments that support greater collaboration and innovation across diverse disciplines.

SBE: The future of work at the human-technology frontier is likely to be characterized by a harmonious integration of technology that supports the holistic needs of workers. As we move forward, technology will play a crucial role in enhancing work experiences, promoting well-being, and facilitating work-life integration. This will help establish sustainable partnerships between humans and technology, creating a more balanced and productive work environment. Emerging technologies like wearable systems, such as smart watches and smart glasses, will revolutionize how work is done by enhancing communication, collaboration, and productivity. These devices, combined with automation, will streamline processes and provide real-time data insights, allowing for more informed decision-making. However, this technological advancement will also require workers to adapt to new

ways of working and acquire additional skills to remain competitive. Continuous learning and upskilling will be essential as teams adapt to changing structures and diverse membership, driven by technological advances. Ultimately, the goal is to leverage technology in a way that supports workers and promotes a healthy work-life balance, fostering a more humane and effective work experience for individuals and organizations alike.

We cannot be sure the extent to which ChatGPT-4 may have drawn upon other sources in addition to the uploaded texts, and we might imagine that chatbots may be biased in favor of artificial intelligence, given that is what they themselves are. Of course, the full texts of the abstracts are freely available at the NSF website, and as the grants are completed the researchers will add public reports with links to publications that resulted from the research. In its current form, ChatGPT limits the size of each uploaded file, so for both CISE and ENG it was necessary to upload three files and tell the bot to combine them in processing questions, so the current total of 71,969 words already poses challenges. Yet it made sense to at least begin a critical analysis by asking the simulated CISE and SBE directorates, "How would you respond to the many people who worry that artificial intelligence will be harmful for workers?" Often, the chatbot "resolves" a question by editing it, and in this case asked itself: "How would a response be formulated to address the concerns of people who worry that artificial intelligence will be harmful for workers?" Here are the responses:

CISE: It's understandable to have concerns about the impact of artificial intelligence on the workforce. However, it's important to consider the potential benefits that AI can bring, especially when implemented thoughtfully and with a human-centered approach. For instance, AI can enhance disaster-management job opportunities for vulnerable groups by creating more roles and improving outcomes. By prioritizing worker mental well-being and focusing on collaboration, AI technologies can be designed to support workers rather than replace them. Moreover, AI can play a significant role in improving the skills and capabilities of marginalized workers, providing them with enhanced opportunities and creating a diverse ecosystem of artisanal enterprises. This not only helps in preserving jobs but also in uplifting communities by improving their financial status and quality of life. Overall, while it's crucial to address and mitigate any potential negative impacts, the thoughtful integration of AI can lead to a future where technology and humans work together harmoniously, enhancing job opportunities and improving well-being across various sectors.

SBE: It's understandable that concerns about artificial intelligence and its impact on the workforce are prevalent. However, AI has the potential to significantly enhance the work environment and improve the lives of workers. For instance, AI-augmented collaboration tools can be developed to ensure inclusivity, providing equal access to teamwork experiences for individuals with different abilities, such as those who are blind or have low vision. This fosters a supportive and inclusive work environment. Moreover, AI can be used to create intelligent team facilitators that enhance team coordination and performance, while also reducing worker burnout. By streamlining communication and task assignment, AI can improve overall team dynamics and productivity, ultimately contributing to worker well-being. Additionally, AI technologies can be tailored to meet the diverse needs of workers across various domains. By understanding the specific contexts and challenges faced by different workers, we can design technologies that enhance work experiences and support work-life integration. In summary, while it's important to address concerns about AI, it's equally crucial to recognize its potential to create a more inclusive, efficient, and supportive work environment.

Given that the first sentences are identical, and the conclusions are similar, we may suspect - or more objectively hypothesize - that the chatbot's ideological perspective is based on the values of its developer, OpenAI, which seems to have begun as an idealistic social movement, evolved into a corporation, and often been the target of public criticism. As a very preliminary way of clarifying the hypothesis, on October 16, 2024, I entered the text from Wikipedia's article about OpenAI into its chatbot.²⁹ Then I asked the bot: "In what ways is OpenAI controversial?" Its responses seemed rather honest:

OpenAI has faced several controversies over time. One key area of concern is related to content moderation and the challenges in ensuring that AI technologies are used ethically and responsibly. There have also been issues regarding a lack of technological transparency, where some critics argue that more openness is needed about how AI models function and make decisions. Additionally, OpenAI has been involved in discussions about non-disparagement agreements and copyright infringement, which have sparked debates about the ethical and legal aspects of AI development. Furthermore, there are concerns about GDPR compliance, particularly how data privacy is managed. Lastly, OpenAI's technology has raised alarms about its potential misuse in state-backed influence operations, which underscores the importance of implementing safeguards to prevent AI from being used for propaganda or disinformation.

I asked the bot to explain what "GDPR compliance" means, and it replied somewhat accurately: "GDPR compliance refers to adhering to the General Data Protection Regulation, a comprehensive data protection law in the European Union. It sets guidelines for the collection and processing of personal information from individuals who live in the EU. Compliance with GDPR involves ensuring that personal data is handled with transparency, security, and respect for privacy, giving individuals more control over their personal information." But the Wikipedia page mentions GDPR in the context of a case in which the problem involved false information about a person, not privacy, and difficulty for the client to get the data corrected or even learn more about what had actually happened. However, in my own experience using ChatGPT-4 to enhance my own work, I have often detected errors I could correct in real-time by chatting with the bot about the error before asking my next question. But the system works best during the original session when I uploaded the file, and only some of the derivative material is preserved for future sessions. In social media more generally, critics and government officials seem ready to demand that the companies operating them be more responsible in blocking false information, yet the computational systems may not be capable of meeting such ideal goals in their currently early state of technical development.

4. Observation of Early Research Results

A collaborative pair of SBE's 2023 core FW-HTF grants share abstract text that includes this remarkable but apparently true observation: "In the past two years, artificial intelligence (AI) tools, such as ChatGPT, have revolutionized the software industry."³⁰ In October 2024, a year after the grants were made but three years before they are scheduled to conclude, already links to four publications had been added to their NSF abstracts. We must watch the progress over the coming years, and the initial research explored communication problems between students and chatbot-like computer programming systems and ways to improve their large language models to render them more comprehensible to inexperienced users.

In development since 2013, the NSF Public Access Initiative has increasingly supported free public access to peer reviewed publications based on NSF-funded research.³¹ While one can search for these publications from the grant abstract system,

there is also a search engine at NSF Public Access Repository, into which I entered “future of work” in mid-October 2024 and found 186 articles, although some were in preparation and not yet fully linked, and many were only approximate matches, for example containing just “future work,” while many others were unrelated to FW-HTF. The system allowed downloading a spreadsheet which I sorted by grant number for the 103 that had that ID, and searched all titles and some abstracts. That quickly highlighted one of the Convergence Accelerators in Table 2, Competency Catalyst, that was now complete, and had received a total of \$7,092,926 over its two phases. While research was involved, this was more of an applicational project, developing a user community and an AI-enabled communication system to support its goals. That explains why management of the large cooperative agreement was moved to the new Directorate for Technology, Innovation and Partnerships that launched in 2022 and today proclaims: “Over the past two years, NSF’s nascent and growing Directorate for Technology, Innovation and Partnerships (TIP) - together with the rest of NSF - has worked to foster innovation ecosystems, accelerate technology translation and development and grow the STEM workforce.”³²

The final outcome report from Phase I began: “The Competency Catalyst (C2) Phase I proposal outlined a vision of dynamic partnerships between postsecondary education institutions, training providers, and industry, in which education and training programs are continually aligned with the competencies required by jobs. Our goal was to catalyze a marketplace of applications built on open competency and skills data, and our primary planned activity was developing an AI-enabled Competency Catalyst that could gather and analyze the competencies and skills data relevant to talent pipelines in locally relevant terms.”³³ The Phase II outcome report began: “The goals of the Competency Catalyst were: (1) help employers communicate upskilling needs to college continuing education departments; (2) help colleges respond with offerings that meet those needs; (3) provide more opportunities to under-served worker populations by focusing on skills rather than degrees and past job titles; and (4) improve training efficiency and effectiveness by aligning college offerings with employer skills requirements.”³⁴

A rather different example of connected projects was discovered because the outcome report of a grant titled Integration of Computational Thinking and Science Using Culturally-Based Topics said it prepared for a later FW-HTF grant titled: Race, Gender and Class Equity in the Future of Work: Automation for the Artisanal Economy.³⁵ The Future of Work abstract explains: “AI is poised to eliminate millions of jobs, from finance to truck driving. But artisanal products and labor - such as handmade textiles, furnishings, adornments, foods, and repair shops - are valued precisely because of their human origins, and thus have some inherent ‘immunity’ from AI job loss. And they are often more enjoyable. While many of the jobs AI can (and should) replace are dull or dangerous, artisanal labor is at the other end of the spectrum: some of the most satisfying professions possible.”³⁶ The researcher, Ron Eglash at University of Michigan, explored how traditional crafting skills could retain their humanistic values while enhanced by AI and becoming profitable within today’s economy.³⁷ His visionary perspective asserts:

Most of our problems are the result of an economy focused on extracting value. We can divide that into three categories: extracting ecological value (over-use of a source like forests and fishing grounds, or over-use of a sink like carbon); extracting labor value (dull office work and assembly lines); and extracting social value (colonization of our social networks and physical communities). Capitalism extracts value for corporations, and bureaucratic communism extracts value for the state, but both are equally harmful. When value is alienated from the regenerative loops that created it, the damage can be devastating. A better model can be found in the Indigenous traditions: rather than value alienation, they practiced value circulation. These “bottom-up” systems for returning value in unalienated forms can be applied to our contemporary societies using technologies such as peer-to-peer production, platform cooperatives, computing for community-based economies, agroecology, and new

forms of “DIY citizenship” ranging from feminist makerspaces to queer biohacking. We refer to these as technologies for generative justice.³⁸

Conceivably, if we have entered the post-industrial era of civilization, many of our institutions might need to return to their pre-industrial forms (Calvert 2024). Clearly, revolutionary concepts like Competency Catalyst and Generative Justice deserve to be considered in this era of global chaos, yet it will be difficult to evaluate them without a great deal of research results, often produced by less ambitious projects. The concept “Automation for the Artisanal Economy” deserves extensive new research, but also links to a somewhat problematic past NSF initiative to develop 3-D printing and related technologies in local makerspaces or small-scale production facilities, called the Maker Movement. Yes, much good technology was developed, but not the new forms of social organizations that would be required to replace much global mass production with local crafting communities.

On June 17, 2014, president Barack Obama proclaimed that the following day would be a National Day of Making: “Today, more and more Americans are gaining access to 21st century tools, from 3D printers and scanners to design software and laser cutters. Thanks to the democratization of technology, it is easier than ever for inventors to create just about anything. Across our Nation, entrepreneurs, students, and families are getting involved in the Maker Movement. My Administration is increasing their access to advanced design and research tools while organizations, businesses, public servants, and academic institutions are doing their part by investing in makerspaces and mentoring aspiring inventors.”³⁹ A decade later, after two other presidents who did not promote the Maker Movement and a pandemic that discouraged people from working together in small makerspaces, large-scale mass-production corporations had not lost dominance over the manufacturing workforce. While NSF continued to support fundamental research to develop the technologies, led by the Engineering directorate, its activities tended to conceptualize the Maker Movement as an educational tool.

Table 3 reports that the Undergraduate Education division invested \$199,185 in FW-HTF exploration in fiscal year 2017, and that supported two related workshops. The workshop organized by Francis Quek at Texas A&M University aimed “to foster a discussion about the re-conceptualization of wealth creation in economically distressed areas by enabling the production of high quality manufactured goods at scales of hundreds and thousands in many distributed locations, but in an effective and sustainable manner. This approach, called ‘Micro-Manufacture,’ is grounded in technological advances that facilitate customized production of artifacts (e.g., 3D printing, the Internet; mobile devices, etc).”⁴⁰ The workshop organized by Silvia Lindtner at the University of Michigan “aimed at understanding how experiments with new forms of work, such as makerspaces, co-working spaces, incubators, and tech entrepreneurship, are transforming the nature of work, the labor force, and many industries.”⁴¹ Its report explains why research is essential in the areas covered by both workshops:

The rise of unemployment and unstable, precarious work conditions sit in deep tension with growing bureaucratic and corporate interests in automating work across sectors. The question of who defines and understands the risks, impact, and benefits of this rapidly changing socio-technological landscape remains an open question... What alternatives are possible in an age of “no alternative”? Do we have to reconsider what counts as intervention into existing structures and conditions of work and labor in order to challenge persistent inequalities and exclusions? How can perspectives from policy, economics, information technology, critical race studies, and feminist studies form a robust and committed scholarship to “making the ‘future of work’ work”?⁴²

A sense of the broader social impacts of Future of Work research related to rapidly evolving information technologies can be derived from two divisions of the CISE directorate that were actively involved in FW-HTF:⁴³ “Computer and Network Systems (CNS): Supports research on computer systems and networks, hardware and software systems, future-generation computing and communication systems, cyber-physical systems, and secure and trustworthy cyberspace.” “Information and Intelligent Systems (IIS): Supports research on the interrelated roles of people, computers and information to advance knowledge of artificial intelligence, data management, assistive technologies and human-centered computing.”

The grants managed through CNS tended to be complex, indeed based on convergence of multiple fields of science and engineering, but with the clear goal of enhancing the abilities of human workers. For example, a 2018 set of collaborative grants titled *Augmenting and Advancing Cognitive Performance of Control Room Operators for Power Grid Resiliency* planned to “integrate principles from cognitive neuroscience, artificial intelligence, machine learning, data science, cybersecurity, and power engineering to augment power grid operators for better performance,” especially during difficult episodes when electricity utilities were challenged by natural or human-caused “extreme events.”⁴⁴ The abstract of a 2022 set of grants titled *The Future of Trucking: Pathways to Positive Societal Outcomes*, assumes that old-style truck drivers would soon become obsolete, as shipping goods by road would become a “white-collar job, requiring human-computer interaction.” The authors expressed deep faith in their own mission: “This research team effort is motivated by a shared belief that remote operation of trucks is a necessary step in the automation journey and will lead to positive technological, economic, environmental, and societal outcomes.”⁴⁵

The abstract of a 2020 CNS Future of Work grant proclaimed: “To unlock this potential of precision agriculture, educators and scientists are eager to train the future farm workforce.”⁴⁶ However, as a conceptual study published in connection with this project noted, the benefit of precision agriculture seems currently greater for large farms operated by corporations rather than small family farms (Gardez et al. 2022), and many farmers may be deterred from adopting this approach both because they lack funds to buy the necessary hardware and because they lack training in how to apply it. The research is exploring how farmers themselves may be involved in user-centered design of decision support systems, both to improve the useability of the systems and learn how best to educate the users.

Some of the IIS grants depart from the heavy emphasis in government support of research only for manufacturing physical products, not service work or cultural creativity. One project seeks to develop “a new ecosystem for music production to empower future musicians to better leverage Artificial Intelligence (AI) tools in the creation, performance, and dissemination of their music, while also accelerating audio AI research.”⁴⁷ Another project conducted in collaboration with a labor union seeks to understand how to mitigate the harm workers are experiencing as automation handles increasing tasks in hotels, restaurants and other aspects of the hospitality industry: “Large numbers of hospitality workers, who are majority female and from underrepresented groups, are being displaced by these technological changes. Workers’ positions are currently being augmented with algorithmic management and robotic assistance, replacing some jobs and transforming others that cannot be completely automated.”⁴⁸

Especially illuminating is a collaborative, three-institution project named “The Future of News Work: Human-Technology Collaboration for Journalistic Research and Narrative Discovery.” Its abstract provides this background: “Journalism, as an information-based industry and profession, has always been impacted by new technologies, most recently by the rise of the Internet and loss of advertising revenue, as well as the long-standing tension between journalistic values and business interests.”⁴⁹ A traditional response might be to set public policies that strictly limit how much social media can freely quote news without paying the reporters or their original publishers,

and currently there is much concern that artificial intelligence has become a tool for covert copyright violation (Golding 2023; Grynbaum and Mac 2023). But given NSF's commitment to advancing technology, this research project's abstract explains it seeks to "advance knowledge about technology and news work through field studies and user-centered development of interactive tools for supporting journalists in research and narrative discovery." An early publication reports initial progress:

News media often leverage documents to find ideas for stories, while being critical of the frames and narratives present. Developing angles from a document such as a press release is a cognitively taxing process, in which journalists critically examine the implicit meaning of its claims. Informed by interviews with journalists, we developed AngleKindling, an interactive tool which employs the common sense reasoning of large language models to help journalists explore angles for reporting on a press release. (Petridis et al., 2023)

5. Beyond the Big Idea Boundary

A focus on both research studies and teaching efforts funded by the STEM Education directorate could be very interesting, but would require an extensive consideration of the history and recent evolution of its scope, and probably combine all six research BIG Ideas since they all are training future workers. So here we can mention a special kind of 5-year NSF grant that combines research and education, called CAREER, with examples from the two directorates that applied the 063Z reference code to identify nine as Future of Work: Engineering plus Social, Behavioral and Economic Sciences. Currently, only untenured faculty in a tenure-track academic position are eligible, and the grant is intended "to provide stable support at a sufficient level and duration to enable awardees to develop careers not only as outstanding researchers but also as educators demonstrating commitment to teaching, learning, and dissemination of knowledge."⁵⁰

Three of these CAREER grants were made in 2018 by programs in the Civil, Mechanical and Manufacturing Innovation (CMMI) division of the Engineering directorate.⁵¹ Two of them concerned robot-assisted surgery, from a program with this description: "The Mind, Machine and Motor Nexus (M3X) Program supports fundamental research that explores embodied reasoning as mediated by bidirectional sensorimotor interaction between human and synthetic actors. For the purposes of this program, embodiment is defined as the capacity to interact with physics-based environments."⁵² One of the resultant publications explained how such research could evaluate "the feasibility of a handheld surgical tool for meeting the quantified speed and accuracy requirements of a clinical need in non-contact interactions that exceed human limitations" (Davies, Ullah and Kowalewski 2022). The third project was funded by a 2017 CAREER grant that sought to improve the precise design of machinery such as robot hands, based on systematic study of how human hands worked (Won, Langari and Robson 2021).

Within the Social, Behavioral and Economic Sciences directorate, the Sociology program in partnership with Law and Social Sciences supported a 2017 CAREER grant with this title: The Influence of Social Problems on Healthcare and Legal Institutions. The specific problem was the opioid crisis, in which a medication designed to soothe pain had become a major cause of drug addiction: "This project will examine how current efforts to curb the opioid crisis affect healthcare and criminal justice workers... Technology is often considered a panacea for addressing social problems, but this research brings a critical lens to technology, addressing the kinds of unintended consequences that might result from its use."⁵³ One of the publications resulting from this research was based on interviews with professional first responders who dealt with episodes caused by opioids, specifically whether they would administer the controversial drug naloxone, that counteracts opioids: "We find that professionals' willingness to take on new tasks is

largely grounded in how they construct patients as deserving or undeserving of care. Deservingness construction is a constitutive process through which first responders draw on cultural imaginaries about addiction and treatment as well as their own experiences providing naloxone” (Baumgart-McFarland, Chiarello and Slay 2022). This grant was supported by regular program funds, while many researchers directly supported by the Future of Work initiative might have argued that the first responders should follow the advice of some artificial intelligence device they were required to wear.

Another social science CAREER grant predicted that in the future there would be much greater emphasis on “work that combines human and computer capabilities to perform tasks that neither could do alone.”⁵⁴ One result would be *algoactivism* in which workers resist being controlled by algorithms, as reported in a journal article with the stark title, “Algorithms at Work: The New Contested Terrain of Control.” It reported: “We find that algorithmic control in the workplace operates through six main mechanisms, which we call the ‘6 Rs’ - employers can use algorithms to direct workers by *restricting* and *recommending*, evaluate workers by *recording* and *rating*, and discipline workers by *replacing* and *rewarding*” (Kellogg, Valentine and Christin 2020).

A third social science CAREER “explores the development and implementation of Automated Hiring Platforms that use complex mathematical formulas and artificial intelligence when making choices about whom to hire for a job.”⁵⁵ Yes, human executives in an organization may be biased when evaluating applicants for employment, whether by race, gender, or some other characteristic that did not prevent the applicant from gaining the necessary skills or having good character. So, logically, some automated system may have more objective artificial intelligence than the corrupted natural intelligence of the executive. But AI based on past hiring data may simply apply existing bias mechanically, so writing in the *Harvard Journal of Law and Technology*, the researcher argues that any such AI must undergo its own very serious audit (Ajunwa 2021).

6. Conclusion

NSF’s Future of Work Big Idea emphasized two modes of human enhancement: (1) advanced education and (2) partnership with artificial intelligence and other innovative information technology. The phase “future of work” does not automatically limit the conceptual scope to physical engineering applications on paid labor, and we can well imagine a second initiative that removed the emphasis on “the human-technology frontier,” perhaps replacing it with “human-human frontier.” A new and enduring competition could be established alongside the exploratory research efforts, Small Organization Innovation Research. While including some new forms of business, the emphasis would be creating new non-profit institutions, social movements, and residential communities. The acronym, SOIR, is the French word for “evening,” which critics might complain implied humanity is headed toward a night in which engineering progress ended. Whether or not that is true, humanity does seem to need a peaceful revolution in how we organize or lives, to reduce conflict and suffering while enhancing our ability to love or at least to respect each other.

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