Building the Foundational Skills Needed for Success in Work at the Human-Technology Frontier

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Introduction

The proliferation of new technologies has changed the way we live, learn, and work. Although the future of work is unclear, thought leaders, including the National Science Foundation (NSF), assert that artificial intelligence, the Internet of Things, robotics, and machine learning will be ubiquitous in tomorrow's workplaces. This vision of the future includes a new machine age, where various technologies (sensors, communication, computation, and intelligence) will be embedded around, on, and in us; where humans will shape technology and technology will shape human interaction; and where technologies and humans will collaborate to discover and innovate (Mervis, 2016; Van Opstal, Evans, Bates, & Knuckles, 2008). In short—the Human-Technology Frontier has arrived!

Without question, the U.S. workforce will need a new set of skills and competencies to succeed in the future work environments on this Frontier—which feels like it grows closer with each new technological advance—and to move our society forward as a global leader in the 21st century. To ensure the workforce is future-ready, our society will need to address existing challenges related to education for workforce development, economics, equity, and ethics. As our society works to understand and identify strategies to overcome these complex and interrelated challenges, two theories—the Psychology of Working Theory (PWT) (Blustein, 2006; Duffy, Blustein, Diemer, & Autin, 2016) and Social Cognitive Career Theory (SCCT) (Lent, Brown, & Hackett, 1994)—can help us understand and attend to the following key factors in cultivating a future-ready workforce:

- The importance of work to society
- Why work is critical to human identity
- How youth develop their work identities
- Why we should be concerned about making sure that there is decent work for everyone

Both the PWT and SCCT theories argue that because career development is an iterative process that begins early and is nurtured through both in- and out-of-school experiences, we need to start supporting STEM workforce development long before youth reach the undergraduate level. Drawing upon these theories, this paper explores the potential to build on the NSF Innovative Technology Experiences for Students and Teachers (ITEST) program's successful use of a "helix" approach (see p. 24-25), which blends career and content learning to help young people master the foundational skills they will need for work success at the Human-Technology Frontier.

We begin by describing the complexities of the labor market, the current and evolving workplace, social stability concerns related to work and working, the future of work and the implications for developing the future workforce, the challenges of obtaining decent work and broadening participation at the Human-Technology Frontier, and factors affecting STEM career development. Next, we discuss the critical role that the NSF's ITEST program plays in preparing the workforce of the future. To close the paper, we examine what federal agencies, private foundations and other potential funders, and those involved in STEM career and workforce development can do to help guide the next steps in broadening participation and reducing inequality in participation in STEM careers. We also provide a summary of implications for building a workforce that can thrive at the Human-Technology Frontier.

A Close Look at the Complexities of the Future Labor Market

Working at the Human-Technology Frontier will involve creating technologies "to enrich lives in future workplaces and improve workplace efficiency, labor productivity, and economic growth" (Cook, 2016). How our society defines *enriching lives* in future workplaces, and whether all people in the future workforce will experience enrichment, is important. Likewise, it is critical to consider how new technologies that improve workplace efficiency, labor productivity, and economic growth will affect people. Significant changes are very close on the horizon. Uncertainty in how our labor market will respond to these changes reflects the complexity of these issues. A consensus view by some of the most well-established scholars on workforce and labor market issues in a recent report by the National Academy of Sciences (NAS) concluded the following:

> *What happens [to the labor market] depends, in part, on whether new technologies automate and replace workers in existing tasks more rapidly than they create new demands for labor. Which will be the case is difficult to answer, because it is easier to see how new technologies coming down the line will automate existing tasks than it is to imagine tasks that do not yet exist and how new technologies may stimulate greater consumer demand. Further, the future of employment is not only a question of the availability or necessity of tasks to be performed, but how they are organized, compensated, and more generally valued by society. These are matters of business strategy, social organization, and political choices and not simply driven by technologies themselves*" (2017, p. 63).

These issues are of particular importance to organizations such as the NSF, whose division of Education and Human Resources (EHR) has a focus on preparing the future STEM workforce. NSF's ITEST program, funded with H1B Visa dollars, helps pre-K–12 youth develop a strong foundation of deep STEM content and career knowledge and skills, while providing the support systems needed to develop students' interest and persistence in pathways to STEM careers. The ITEST program further prepares youth for work at the Human-Technology Frontier by providing them with experiences that mirror the use of innovative technologies in authentic workplaces, with the intention of preparing them for future STEM work in technology-rich environments.

The aforementioned passage from the NAS report provides a coherent response to the debate about the future of work with respect to technology. The material that we present below, coupled with the quote from the NAS report, offers some important lessons for federal agencies, both public and private foundations, and policymakers. Perhaps foremost in the NAS report is the view that these imminent changes to the world of work, while currently moving ahead without much planning and structure, are likely amenable to broad policy levers. We believe that one of these levers is the intentional use of federal and foundation funds to help steer scholarship, educational policy, and workforce development initiatives in directions that will support systematic responses to automation that value work as a core psychological need and human right (Blustein, 2006; Blustein, Kenny, DeFabio, & Guichard, 2017)

Working at the pre-K–12 level, the ITEST program provides opportunities for youth to engage with innovative technologies that mirror authentic workplaces and to envision themselves in the STEM workplace.

Mapping Technologies: In the GET City (Green Energy Technology in the City) project (2007–2011), carried out in a Michigan Boys and Girls Club, urban minority students participating in afterschool clubs devised an approach for identifying urban heat islands.

Monitoring the Local Environment: In the Student Enabled Network of Sensors for the Environment Using Innovative Technology (SENSE IT) project (2008–2012), Clarkson University and Beacon Institute for Rivers and Estuaries worked with teachers and students at Tech Valley High School in New York to support students in designing, developing, deploying, and testing sensors for measuring water quality in the Hudson (Remold, Vogt, & Parker, 2016).

The Current and Evolving Workplace

Today, the global workplace is undergoing massive changes across nearly all occupational sectors. Within the United States, workers with advanced technology and science skills are in high demand as organizations seek to improve their productivity, creativity, and innovative capacities. At the same time, workers without marketable skills are struggling to earn their livelihoods, often creating work lives out of part-time jobs that pay too little to move into the middle class (Blustein et al., 2017).

A recent report by economists Katz and Krueger (2016) indicates that the majority of new jobs created in the past decade are short-term contract work, contributing to the growing barriers that those without marketable skills face in entering the world of stable and decent work. *Decent work*, a term developed by the International Labour Organization (ILO) (2008), refers to an aspirational standard about work that includes stability, fair wages, social protections, and other features that promote well-being. The impact of automation and outsourcing on the labor market, and the winnowing away of options to secure decent work, is simply unprecedented. Increasingly, workers without advanced skills are sinking into pockets of despair, with increases in substance abuse, alienation, and disengagement (Blustein et al, 2017; Paul & Moser, 2009).

One way of reducing inequality in the occupational world has been to enhance access to fields with current marketplace needs and anticipated growth, such as STEM. The NSF, the U.S. Department of Education, and other research and policy bodies in the United States have continually called for increases in the quality and quantity of students in the STEM workforce pathway, which has already yielded important advances in curriculum innovations and the identification of best practices in education and career development (Blustein, Medvide, & Wan, 2012; Connors-Kellgren, Parker, Blustein, & Barnett, 2016).

Scholars and policy analysts who have been thinking deeply about the Human-Technology Frontier have expressed considerable concerns over the impact of automation on the labor market. Indeed, a debate exists within various social scientific and public policy circles about the potential impact of automation in the world of work. Some scholars have argued that up to 47 percent of jobs in the United States will be replaceable by automation within 10 years (Frey & Osborne, 2013). Other scholars, such as those who prepared the 2017 NAS report, are more cautious in developing precise estimates of the labor market. However, there is consensus that automation is a game changer (Organisation for Economic Co-operation and Development [OECD], 2015, p. 12), with implications for the workplace that will likely be dramatic, yet not easily predictable.

ITEST projects develop and implement professional learning experiences that encourage teachers to facilitate authentic and innovative student interactions with STEM.

Blended Learning: The Build IT Underwater Robotics Scale Up for STEM Learning and Workforce Development project (2009–2015) focused on making an underwater robotics curriculum more accessible to experienced technology education and engineering teachers. At a one-day, in-person workshop, teachers built robots and completed challenges and then participated in follow-up online modules.

Bringing STEM Professionals into the Classroom: The Scaling Up STEM Learning in the VCL project (2009–2014) featured pairs of teachers working with STEM professionals from a range of fields to develop an in-class activity that the STEM professionals would lead while visiting the classes (Vogt, Remold, Singleton, & Parker, 2016a).

Social Stability Concerns within the Context of the Human-Technology Frontier

The academic literature in career and workforce development offers many useful suggestions for systemic interventions, educational initiatives, and workforce development practices to enhance opportunities for individuals and communities to succeed in the labor market. While some economists and policy analysts are advocating for a guaranteed income to ensure survival among those who cannot attain a foothold in the labor market (e.g., see OECD, 2015), psychological research on work and well-being offers some cautionary perspectives (Blustein, 2008; Blustein et al., 2017). Survival needs, naturally, are essential if the economy cannot provide sufficient numbers of decent jobs. In this context, income transfers may become an important solution to ensure survival for all of our citizens. That said, the existing research from psychology and related social sciences underscores that work itself may provide for core human needs, which are integral to our well-being.

In an integration of the research on work and need fulfillment, Blustein (2006) proposed that work optimally may fulfill our needs for survival, social connections, and self-determination. A considerable body of empirical research supports the notion that people report better mental health and physical health when they have access to decent work (e.g., Blustein, 2013; ILO, 2016, Suicide Prevention Resource Center, 2008), thereby reducing economic and social stresses on society. Indeed, extensive research that has documented the impact of unemployment and job loss on people further supports this observation. As reflected in meta-analyses and integrative reviews on long-term unemployment (Paul & Moser, 2009; Wanberg, 2012), adults who have been out of work for six months or more are far more likely to experience mental health problems such as depression and anxiety, as well as interpersonal conflicts. This trend is heightened for men and for individuals from poor and working class backgrounds.

In addition to these problems at the individual level, lack of access to work has a negative impact on communities and societies. Reports by the ILO (2015, 2016) have documented relationships between economic opportunity, as reflected in access to decent work, and social stability. In a similar vein, lack of work has been associated with increased social unrest and community breakdowns, as reflected in Wilson's (1996) classic analysis of urban Chicago after the loss of industrial jobs and in the aforementioned ILO reports. When considered collectively, the evidence from the social sciences is clear and compelling. Work provides access to core psychological needs and provides the glue that helps to hold together people and societies.

As noted, at the present time, people without clearly marketable skills are being marginalized from the workforce. Future projections (Frey & Osborne, 2013; NAS,

2017) are also identifying workforce challenges for people who are currently well-matched for the labor market. Society is at a crossroads now with respect to human welfare and the workforce. If we do not develop enough creative solutions to the challenge of creating new jobs for a workforce that is increasingly embedded with technology, we may face major crises, akin to climate change, that could lead to psychological distress and social breakdowns that are hard to predict.

The Future of Work: Mapping the Human-Technology Frontier

Disruptive technologies (e.g., cloud technology, drones, sensors/biosensors, 3-D printing, automation of knowledge work, renewable energy and energy storage, the data revolution, and advanced robotics) and the increasing affordability and accessibility of these technologies by the general public are transforming life, business, and the global economy as we know it (Kurose, 2016). While "singularity," where computers surpass human intelligence, is many decades away, intelligent systems (Narrow AI) operating effectively and efficiently focused on specific tasks can assist humans in pushing the boundaries of work as we know it (National Science and Technology Council [NSTC], 2016). Machines are now able to defeat humans in games of skill, translate from one language to another in real time, understand the content of photographs and recognize faces, navigate stairs, assemble products, and deliver services. We are now able to converse with machines using ordinary speech, guide computers as they design products to our specifications, and integrate machines into the human body. Driverless cars and trucks, pilotless passenger jets, recreational space travel, smart communities, and smart and connected health are moving closer to consumer markets.

Disruptive innovations (innovations that change the status quo) are bringing about breakthroughs across all industry sectors (Annunziata, 2017). On the biotech front, CRISPR is enabling us to splice genes in embryos, bringing us closer to eliminating inherited diseases such as Parkinsons and intractable illnesses such as HIV (Stockton, 2017). The Internet of Things is connecting people, tasks, and production in a digital infrastructure, while creating a world with more power to solve problems and less need for people to work. Using deep-learning algorithms, machines are creating their own logic drawn from massive amounts of input data enabling them to optimize decision engines with superhuman accuracy and continue to learn from their own conclusions (Howard, 2017). On a daily basis, as these innovations occur, practical applications are changing our lives. In health care, for example, artificial intelligence is being used to predict complications and improve treatment of severe wounds at Walter Reed Medical Center and to reduce hospital-acquired infections at Johns Hopkins. On the transportation front, it is being used in traffic management to reduce wait times, emissions, and energy use (NSTC, 2016).

With advances in the field, machines are now able to see, hear, read, write, and make decisions on their own (Brynjolfsson, 2017). Further experiments in deep learning have shown that machines are becoming more intuitive—as is the case with a robot faced with a pile of laundry. The robot runs through its database of possibilities and, without direction or prompts from a human, makes the determination that the laundry needs folding and folds the laundry. In addition to performing more tasks traditionally considered "human" work, machines are able to take on more of what we have traditionally called "human" characteristics. This is most evident in the work of Dr. Hiroshi Ishiguro, the godfather of humanoids at the University of Osaka in Japan. Dr. Ishiguro's experiments with humanoids are helping Japan embrace social robots to replace human workers as a possible solution to Japan's population decline when the nation will lack sufficient numbers of people to do the nation's work (CBS News, 2017).

The human-machine partnership works both ways. The International Data Corporation (IDC) predicts an era of augmented humanity where the marriage of technology with biology will "take the human mind and body to unprecedented levels of mental and physical capability" (Wong, 2016). Some say we have already entered the "augmented age" where humans are enhanced by working together with machines (Conti, 2017). Indeed, we are already connecting to machines. For example, MIT is integrating technologies with human biosystems through their smartphone-controlling skin tattoo that has pushed technology to the cellular and sub-cellular levels and through their initiative connecting a neural mesh directly to the brain to help disabled people to move objects just by thinking.

With machines gaining insight and making intuitive leaps, the role that humans play at work will change. On the TED Radio Hour from National Public Radio, Marco Annunziati, chief economist at General Electric, describes what human-machine collaboration means for our jobs (TED Radio Hour, 2017) and predicts that the next 5–20 years will bring great changes in the workplace. He visualizes a world where machines, not just computers, but also "locomotives, jet engines, gas turbines, and medical devices are communicating seamlessly with each other and with us.... where machines are not just intelligent—they are brilliant, self-aware, predictive, reactive, and social." He illustrates this through examples of "conditioned-based maintenance," where self-learning machines predict and schedule airline maintenance just before components fail, saving millions in airline costs and reducing the 60,000 flight delays and cancellations annually.

New job opportunities will emerge as humans and machines collaborate to attack previously intractable problems (NAS, 2017). What knowledge, skills, and dispositions will be needed by scientists, engineers, technologists, and technicians who are discovering and innovating in these high-tech environments and who are building and maintaining the technologies that are driving innovation in this new world of work? How do we ensure that future workers develop the foundational skills and persistence needed to progress on pathways toward future careers and decent work of all sorts?

How Do STEM Industry Leaders Envision the Future of Work?

As discussed above, the future of work at the Human-Technology Frontier will include an increase in artificial intelligence and machine learning, with humans and computers partnering to perform routine tasks, conduct research, innovate, and problem solve. Although some jobs will disappear and others will be replaced, the most common changes will occur as work tasks are increasingly shared between humans and machines and in work teams that include machines. Fewer people may be needed to "work;" therefore, broadening participation in opportunities for skilling and up-skilling will become essential if we are to preserve a diverse workforce capable of breakthrough innovations. Preparing for lifelong careers, as we have known this process since the mid-20th century, may be a relic of the past. Core and foundational skills that can apply to a variety of specializations and contexts, and personal attributes that indicate an individual's ability to adapt and learn, will be valued. Dynamic interdisciplinary teams, with team members (including machines) moving in and out of work team activities as needed, will drive innovations. Artificial intelligence and machine learning will exponentially increase the speed of innovation and change.

To further describe work environments at the Human-Technology Frontier, we reviewed additional reports on the future of work (Mervis, 2016; NAS, 2017; OECD, 2015). We updated the research through interviews with prominent individuals currently working at the edges of this Frontier. These experts hold positions in national defense, aeronautical engineering for space travel (SpaceX), advanced technology companies, and research (R. Coppola [personal communication, March 9, 2017]; M. Beyer [personal communication, March 31, 2017]; R. Brothers [personal communication, April 3, 2017]; S. Vinter [personal communication, April 7, 2017]; C. Fadel [personal communication, April 21, 2017]; & E. Ferraro [personal communication, April 26, 2017]). Based our interviews and research, we found that work environments at the Human-Technology Frontier are likely to possess the key characteristics outlined below.

Predominance of dynamic interdisciplinary teams: Because innovation at the Human-Technology Frontier will come from a convergence of disciplines, future work will be done in dynamic interdisciplinary teams that include machines. Some team members will bring deep content knowledge; others will contribute sophisticated technical skills; and still others will be able to synthesize and get the best synergies among the different actors moving in and out of projects as needed.

Focus on data: "Our world economy and jobs are increasingly shaped by data and by the knowledge and skills required to use it effectively. Effective use of data empowers us to make objective evidence-based inferences and fundamental decisions affecting our lives, both as individuals and among societies" (Oceans of Data Institute, 2016). Scientists, engineers, and business leaders will use continuous streams of data between and among humans and machines to create, innovate, and make decisions to optimize products and services. As we move toward biological- and chemical-based innovation, working with big data will allow us to expand our mathematical models by putting together life science models based on observable trends. Managing networks of connected devices will change relationships among organizational partners. Data publicly available within minutes of capture will accelerate the pace of innovation and change.

Artificial intelligence: Artificial intelligence will continue to enable machines to "understand" complex things that people cannot reason about as quickly. Computers will be better than people will be at doing many tasks. Computers will detect processes and make inferences about issues that humans will not know about. They will inform and facilitate how people make decisions. Computers are going to be able to provide insight into data that will direct what people do. The question will be how machine intelligence can complement the workplace in ways that allow people to do the things they do best and help people thrive in a workplace in a way that allows computers to do the things they do best.

Ubiquitous computational thinking: As humans and machines become interdependent and share more work tasks, more workers across all industry sectors will engage in computational thinking (CT). CT is already recognized as essential to creativity and innovation in a world driven by technology (Cuny, Snyder, & Wing, 2010; Isbell, Stein, Cutler, Forbes, Fraser, Impagliazzo, & Xu, 2009; Moran, 2016; President's Information Technology Advisory Committee [PITAC], 2005; Van Opstal et al., 2008; Wing, 2006, 2016).

Engineering design/design thinking: Engineers innovate scientific discoveries. As the pace of technology, discovery, and innovation increases, so will the need for engineers who can translate fundamental experiments into products and services that have societal impact. Design thinking will play a significant role in the future of work, not only because it captures the process by which ideas are translated into products, but also because it provides a common language and process for engineers and team members from other disciplines to define a problem and develop pathways toward a solution.

Convergence and focus on life sciences: Innovation in data analytics, computer science, mathematics, and hardware will continue to make advances in life sciences and genomics possible. Without breakthroughs in those fields, we would not have achieved the current progress we have made in areas such as cancer research and brain science. As would be expected at the Human-Technology Frontier, current trends show a move toward engineering in the life sciences; more life sciences patents are now being issued than in physical sciences, and significant innovations are taking place in biomedicines and biochemical engineering.

Cybersecurity/working within insecure systems/boundaries: Valuable employees will know how to keep their data secure and create comfortable technology environments in which to work. This will become increasingly challenging as we move into an era where, no matter how hard we try, our technology systems will not be secure. Workers will need to continually assess their levels of risk, learn to function and get comfortable working in an insecure computing environment, and learn how to code when our environment cannot be trusted. To make judgments in these areas, workers will need a solid understanding of security and cybersecurity.

Blurred boundaries between humans and machines: As both machines and humans evolve, the boundaries between what humans do best and what machines do best will blur. As artificial intelligence becomes ubiquitous, these boundaries will change even more rapidly. Workers will need to gain a deep understanding of computer technologies so that they can determine what they do better than the machines and create environments in which each builds on the other's capacities. Creativity and innovation at the Human-Technology Frontier will require individuals to develop a deep understanding of how technologies work as well as the knowledge/skills to use technologies, modify them to their specific purposes/interests, use them to create and innovate products and systems, and develop them to meet societal needs.

Education and training emphasis on problem-based learning and solving real-world problems: Strong "real-world" problem-solving skills will continue to be in high demand—even as many of the problems we need to solve grow more complex and become entrenched in technology. Currently, employers agree that their most valuable employees are those who are able to draw upon their intellectual, academic, technical, and social skills to address challenges in the workplace, and resolve those challenges in ways that save the company time and money (Economist Intelligence Unit, 2015). Looking to the horizon, these employee competencies will not diminish in value.

Increased focus on continuous lifelong learning: Continuous learning is already an integral part of the workplace driven by technology. As more work occurs at the intersection of humans and machines, the need for continuous lifelong learning will increase (Friedman, 2015). We are already experiencing a shift in expectations for learning at work. While informal learning in the workplace is recognized and highly valued, employers are increasingly expecting employees to complete continuous formal learning on their own time. As humans and machines become interdependent, organizations will be pressured to stay at the forefront of change not only to gain a competitive edge, but to also survive. New technology innovations will provoke an immediate rush of self-directed learning by employees to learn and apply those innovations, but also to understand them, learn from them, and build off them. Increasingly, continuous learning will become a responsibility of the employee who will identify and pursue new knowledge to learn and skills to develop. Companies will support this self-directed, continuous learning of employees; however, they will still expect that formal learning take place during the employees' personal time. The need for continuous learning in the workplace is bringing about a shift in expectations about the nature and purpose of education. Employers will focus more on educational outcomes based on production and not learning. Rather than use a college degree as a marker of achievement and future production, employers will look at the portfolios that students complete as part of their studies. What products did they build as part of their educational experience? To what extent will those projects carry forward as business opportunities?

Ethics at the Human-Technology Frontier: Increasingly, researchers and industry stakeholders are turning their attention to ethical implications and potential risks facing humanity, particularly existential risk from advanced artificial intelligence and other technologies. Technologies are not mere artifacts. They are social, cultural, and economic phenomena that cannot merely be deployed but must be integrated into society, thereby fundamentally changing society. Emerging technologies at the Human-Technology Frontier include, but are not limited to, information technology, genomics, biotechnology, synthetic biology, nanotechnology, personalized medicine, stem cell and regenerative medicine, robotics, and geoengineering.

Organizations such as the Future of Life Institute, its founders—including MIT cosmologist Max Tegmark and Skype co-founder Jaan Tallinn—and its board of advisors, which includes cosmologist Stephen Hawking, are mobilizing to tackle these kinds of challenges. FLI is supporting research and initiatives for developing "optimistic visions of the future," including positive ways for humanity to steer its own course in a rapidly changing, technologically advanced world. FLI and similar organizations are particularly focused on the potential risks to humanity from the development of human-level artificial intelligence. The many hotly debated topics in the field include ensuring that future artificial intelligence and technology systems are robust and immune to hacks, growing our national prosperity through automation while still preserving people's resources and purpose, realizing what set of values should align with work at the Human–Technology Frontier, and what legal and ethical status artificial intelligence should have.

The implications of artificial intelligence, and its ability to mimic human intelligence, may require more attention on a federal level. In a report released by the White House on the current and future state of artificial intelligence, leading innovators considered not only the technology that will drive artificial intelligence, but also the ethical considerations that must fuel its growth (NSTC, 2016). How should we regulate automated cars to ensure public safety? How can emerging technologies be used to streamline government operations and provide new jobs for people? Is medical research that mines large databases containing the genomic data of millions of people an invasion of privacy? Are geoengineering technologies for addressing climate change justified or more dangerous than climate change itself?

In the coming decades, experts predict that emerging technologies, such as machine learning, will continue to make great strides on a number of human tasks. Many areas of public policy, from education and the economic safety net to defense, environmental preservation, and criminal justice, will see new opportunities and new challenges driven by the continued progress of artificial intelligence.

Public policy must evolve to adapt to these challenges. It is crucial for future innovation to be done in an ethical way in order to build a future in which humans are not competing with machines or being overtaken by robots, but instead entering into a new era of collaboration that frees up the human mind for more emotionally meaningful tasks. As we create new technologies that will alter the fabric of our daily lives, we must simultaneously implement policy solutions that will protect against creating a world where humans are trumped by the very machines they have created. Developing and studying machine intelligence can help us better understand and appreciate our human intelligence. Used thoughtfully, artificial intelligence can augment our intelligence, helping us chart a wiser way forward. There is a great deal of work to be done if humanity is to successfully navigate the promise and the perils of the Human-Technology Frontier.

What Are the Implications for Development of the Future Workforce?

To create and innovate in the environments described above, all industry sectors will need a new type of worker. As a baseline, that new worker will require a deep knowledge of science, technology, and engineering coupled with the technical skills and understanding of how computers, robots, and other machines work. They will need to know how to keep their data safe, possess skills in interpreting data and telling their story, and have a solid grounding in CT and the ability to use, modify, and create technologies that will have societal impact. In addition, the new worker will need to be comfortable sharing work tasks with machines. This technological grounding, however, will not be enough to succeed. Optimal new workers will be curious, self-directed, and resilient. They will be lifelong learners willing to be disruptive and innovative, while also being cooperative and interpersonally competent. They will think outside the box; solve problems and risk failure; work in dynamic, cross-disciplinary teams; and lead those teams to consensus. All of their work will be characterized by insight, interpretation, diligence, persistence, and cooperation.

Since 2003, over 300 ITEST projects have worked with 566,500 students and 16,900 educators around the United States. Each project provides participants with opportunities to build the competencies needed to allow them to pursue STEM careers, develop transferable skills, and find decent work at the Human-Technology Frontier.

The Network Science Project allows students and teachers from urban schools in Boston and New York City to build CT skills by learning about network science through collaborative research projects that draw on publicly available data and open source software..

The MATE ROV Project works with middle school students, teachers, and parents to develop engineering design and CT skills through designing underwater robotics that solve real-world problems. Student teams collaborate in an annual competition demonstrating their products.

The Big Data for Little Kids Project of the New York Hall of Science is deepening understanding of how young children ages 5–8 experience data modeling in an informal setting through engaging in the data cycle (forming questions, collecting, analyzing, organizing, and interpreting data) and how parents engage with children in data-inquiry activities in informal learning environments through a six-week workshop experience for children and their parents. The families work together in hands-on activities that use sorting, measuring, variation, interval and categorical data, and data visualizations, all related to the overarching question, "What makes an exhibit?"

What Does It Mean to Broaden Participation at the Human-Technology Frontier?

The rapid and somewhat unpredictable move toward an uncertain future of work is even more daunting for students and workers with skill sets different from those that have been described in the previous section. As noted, new skills and information will be needed for people to find a home in a labor market infused with STEM knowledge and technology. A major feature of the current workforce and labor market is growing inequality, which is endemic in the United States and many other regions of the world (ILO, 2016; OECD, 2015). A major dividing line in growing inequality is an unfortunate reality that many people are leaving high school without adequate skills to find a secure and decent job. It is clear that numerous factors are contributing to growing inequality; however, education and career development are clearly implicated as processes that are affected by disparate resource allocations, which in turn, shape and influence youth, often with profoundly constraining impacts. Indeed, the demand for more specialized skills, particularly in STEM and technology, is increasingly predicted to enhance inequality, particularly among populations in the United States that are under-resourced and marginalized by poverty, racism, and other forms of marginalization (NAS, 2017). As we propose in this report, this growing divide is a space in which the NSF can be quite effective, exerting a policy lever that can have long-lasting and positive impacts for students and communities who are at even greater risk for being forgotten in the workforce of the near future.

As indicated earlier, one of the most disconcerting trends in the infusion of technology into the workforce is the automation of lower skilled and semi-skilled occupations, resulting in a massive shift in the requisite skills needed to enter and succeed in the labor market (NAS, 2017). The traditional role of lower skilled work as a steppingstone to the workforce is being replaced by education and training, which is increasingly requiring more sophisticated skills, particularly in numeracy and quantitative reasoning (NAS, 2017).

The rise of inequality in the labor market is highly challenging, with major consequences to both political and social trends in many societies around the globe. Within the United States, the rise of inequality is reshaping our society with a growing contraction of the middle class (Stiglitz, 2015). Education and training have long been viewed as important means of enhancing social mobility. The NSF's commitment to increasing equity in access to the STEM workplace is a good example of efforts to broaden participation in undergraduate and graduate programs, preparing students for immediate transition into the STEM workforce (e.g., NSF INCLUDES, ADVANCE, and Scholarships in STEM). As indicated earlier, the ITEST program reflects a concerted effort by the NSF to develop new evidence-based pre-K–12 curricular and programmatic initiatives that optimally may enhance participation of girls and historically marginalized students (e.g., youth of color and those from low-SES backgrounds) in the STEM educational pipeline. We believe that this expanded portfolio will need to include programs that focus on both STEM and new workplace contexts that may emerge out of the human-technology interface. In addition, we strongly advocate that the NSF fund applied and theory-building research that can identify the individual and contextual factors that may support people and communities as they grapple with a society with a radically shifting occupational context.

Context, Constraints and Psycho-Social Factors in Developing Careers at the Human-Technology Frontier

The career development literature is clear about the factors that predict access to the world of work, which include factors related to individual attributes and broader social and economic contexts. As noted, two major theories that have inspired research in our ability to access stable and decent work are Social Cognitive Career Theory (SCCT) (Lent et al., 1994) and the Psychology of Working Theory (PWT) (Duffy et al., 2016). SCCT emphasizes the impact of self-efficacy (i.e., individuals' perceptions about their competencies), outcome expectations (i.e., beliefs about the outcomes of performing particular behaviors), and goal selection in regulating the career decision-making process (Brown & Lent, 1996; Lent & Brown, 1996; Lent, Brown & Hackett, 1994, 2000). The more recently developed PWT builds off research from vocational psychology, multicultural psychology, intersectionality, and macro-levels analyses of work. Devised to be pertinent in the current economic climate and changing world of work in the 21st century, PWT proposes that contextual factors may be more fundamental to occupational attainment than has been previously theorized. Central to this theory is an empirically verified (e.g., Douglass, Velez, Conlin, Duffy, & England, in press) model that both highlights the role of contextual factors— economic constraints and marginalization, in particular—and intends to foster interventions that increase access to decent work. PWT and the research emerging from this new initiative are clearly pointing to the importance of K–12 education, which can mitigate some of the contextual factors (e.g., lack of social support and access to resources) while strengthening students' career adaptability (capacity for exploration and planning) and sense of proactivity.

Economic constraints begin in early childhood: Although the notion of the American dream is widely endorsed, an extensive body of literature points to the impact of socioeconomic status at birth on academic achievement (e.g., Duncan & Murnane, 2014), occupational attainment (e.g., Diemer & Ali, 2009), and socioeconomic status in adulthood (Lott & Bullock, 2007). Economic constraints early in life can limit parents' abilities to provide the necessary supports that facilitate vocational success for their children later in life. In fact, experiencing economic constraints during early childhood has a greater impact on occupational outcomes in adulthood than experiencing economic constraints at any other time in life (Huston & Bentley, 2010). Specifically, through mechanisms such as limited access to stimulating early childhood environments, lower quality education, and less access to social capital, children living in low-income families have disproportionately diminished access to opportunity than their higher- income peers. In addition to the clear impact of economic constraints in early childhood, PWT highlights the critical role that economic constraints play throughout the life span (Blustein, 2006; Duffy et al., 2016). Importantly, PWT distinguishes between perceived social class and economic constraints. Economic constraints reflect a lack of access to material resources, whereas social class is a perceived social identity. Although classism and one's perception of one's own social class likely impact access to opportunity, PWT posits that restricted access to material resources independently and substantially limits social mobility.

ITEST projects broaden participation by designing projects relevant to youth and providing tools and skills to build on their strengths and overcome constraints.

Modifying PWT for Youth Experiences: The PWT was developed by building on experiences of adults in the workplace, but the ITEST project IT and College Pathways through Application of Technology to Explore Urban Ecological Challenges (2009–2014) adapted it to the experiences of youth exploring careers rather than pursuing careers. For the youth in that project, social connectedness emerged as the most salient concept having an impact on their interest in future STEM careers (Mark, 2016).

Place-Based Pedagogies: Projects designed around a community issue can help youth understand STEM through real-world applications relevant to their everyday lives. For example, the GET City project (2007– 2011) set up a "Green Club" in afterschool programs at Boys and Girls Clubs in a depressed urban area in Michigan. The African American student participants studied the impacts of energy production and consumption in their homes, communities, and cities.

Valuing Indigenous Knowledge: In the Back to the Earth project (2012–2016), youth delved into the historical significance for their tribes of particular local watersheds. They learned how these watersheds had deteriorated over many decades as Native people struggled to adapt, first to the influx of European settlers and later to the U.S. government's land and water use policies that conflicted with tribal practices. The students then developed approaches for restoring the watersheds (Vogt, Remold, Singleton, & Parker, 2016b).

Marginalization and multiple social identities: A second and related contextual factor that impacts career development is marginalization. Social identities (e.g., race, ethnicity, gender, sexual orientation, and gender identity) interact with one's social context such that both implicit and overt discrimination and prejudice can substantially impact the course of one's career. One example of how social identities play out in the world of work is through the segregation of the workforce according to gender (Kantamneni, 2013) and race (Berdahl & Moore, 2006). Women are implicitly and explicitly discouraged from entering certain male-dominated industries, such as engineering, due to limited opportunities for female employees' advancement and the prevalence of sexism (Fouad, Singh, Cappaert, Chang, & Wan, 2016; Kantamneni, 2013). Intersectionality Theory (Cole, 2009), which has informed PWT, accounts for the fact that individuals simultaneously occupy multiple social identities that intersect to create a unique experience in the workplace, the job market, and academic settings. For example, some scholars have argued that women of color who face both gender and racial discrimination experience "double jeopardy" in the workplace (Berdahl & Moore, 2006). A 2014 Department of Labor report indicates that overall, U.S. full-time female workers earn 78.6% of what U.S. full-time male workers earn when comparing median annual salaries. When accounting for race and ethnicity, wage disparities reveal the compounding effects of gender and both racial and ethnic prejudice: Hispanic women earn 54.6% percent of what white men earn and African American women earn 60.5% (U.S. Department of Labor, 2014). Although it is impossible to "tally" the effects of various social identities on career advancement, acknowledging the unique experiences of individuals who occupy multiple social identities in context, as proposed by PWT, is crucial to understanding how marginalization impacts career development.

Education can play an important role in mitigating some of these challenges. For example, interventions throughout K–12 education can help reduce the impact of gender-based socialization and race-based socialization, which affect students' choices of classes and long-term career plans. Education and career development interventions that provide relevant and rigorous connections between students' lived experiences and STEM skills can reduce the impact of race- and gender-based socialization, which often circumscribes students' considerations of STEM subjects and careers (see Byars-Winston & Fouad, 2008 and Ceci & Williams, 2007 for further details). As we indicate in this report, ITEST programs and similar initiatives can provide the framework for evidence-based interventions in K–12 contexts that can enhance opportunities for girls and students of color to overcome the daunting obstacles that exist in their environments.

Social support outside of work and school: Social support is another contextual factor that plays a crucial role in transitioning to a career. SCCT posits that social support positively influences career development, which broadly accounts for supports and barriers in one's immediate context. PWT pays explicit attention to social support as a potential moderator on the influence of contextual barriers on obtaining decent work and work fulfillment. A large theoretical and empirical body of literature points to the importance of relationships outside of work (Blustein, 2011) and school (Rueger, Malecki, Pyun, Aycock, & Coyle, 2016) for facilitating healthy functioning in work-related environments. Attention from important adults during youth is especially important to fostering that young person's developing a sense of purpose (Liang et al., 2017), which predicts a host of positive outcomes from school engagement to future success (Damon, Menon, & Cotton Bronk, 2003). Among youth who experience a high level of contextual barriers, attention from adults may be compromised for a number of reasons, including inflexible work demands among low-income parents (Heymann & Earle, 2000) and limited access to teachers due to school overcrowding (Fine, Burns, Payne, & Torre, 2004). Thus, extant literature indicates that the role of social support in shaping vocational outcomes may be particularly important, though potentially less available, for young people who experience high levels of contextual barriers to accessing decent work. Here again, K–12 interventions can provide students with the skills to seek out and sustain social support, including mentoring, which can provide such essential protective factors in the face of a challenging transition to decent work.

Factors affecting career development begin early: As we have progressed in our search for explanations of career choice and success, we have learned that career development is a lifelong process that begins in the home, is nurtured throughout school life, and manifests in changing adult career choices. For the past 50+ years, developmental theorists have agreed that career development proceeds along a continuum of iterative experiences (age 5 to adult). Throughout this continuum, individuals optimally develop, assess, refine, and act on their career interests, skills, and knowledge. Thus, occupational decision making is a developmental process that addresses complex issues of social and psychological development (Crites, 1969; Ginzberg, 1972; Ginzberg, Ginsburg, Axelrod, & Herma, 1951; Havighurst, 1953; Holland, 1997; Roe, 1957; Super, 1951), some of which are described in Table 2. Developmental theorists have also agreed that students experience stages of career development throughout their pre-K–12 experiences. These include career awareness usually developed at the elementary school level, career exploration during middle school, and career preparation beginning in high school, when students make preliminary career decisions related to course and program selection. SCCT theorists (Lent, 2005; Lent et al., 1994, 2000) further developed this work to recognize the mutually influencing relationship between people and their environment (Leung, 2008). Niles and Amundson (in Niles, Amundson, & Neault, 2011) added yet another dimension by developing the Hope-Centered Model of Career Development (HCMCD), proposing that hope plays an important role in career development and decision making and that highly hopeful youth seem to achieve higher performance in their academic studies and their careers.

Psychosocial factors shaping STEM career development: These contextual factors are important to our discussion as they are present throughout the formative years of childhood and play a central role in how individuals are motivated to make and pursue career choices (Duffy et al., 2016). Complementing the PWT contextual factors listed above are relevant psychosocial factors that have been associated with developmental progress in both education and career development (Table 1). These include self-efficacy and outcome expectations, proactive personality, work volition, career adaptability, and critical consciousness.

Table 1. Foundations of a Successful STEM Workforce: Psychosocial Factors Shaping STEM Career Development in K–12 Education

Psychosocial Factor	What is it?	Why is it important?
Self-Efficacy and Outcome Expectations	Self-efficacy involves a dynamic set of beliefs or judgments about one's "capabilities to organize and execute courses of action required to attain designated types of outcomes" (Bandura, 1986, p. 391; quoted in Lent & Brown, 1996). Outcome expectations refer to an individual's belief about the consequences of taking particular courses of action (Lent et al., 1994). Self-efficacy and outcome expectations are shaped through experience (Lent et al., 1994).	STEM self-efficacy is a belief that an individual can become a STEM professional or technical worker. Youth with STEM outcome expectations understand that their actions to support STEM learning experiences can lead to STEM career outcomes. K–12 programs that include activities to promote STEM self-efficacy and STEM outcome expectations can have a positive impact on STEM career development by helping youth develop interests in pursuing STEM careers and persisting in their efforts.
Proactive Personality	Proactive personality is "a disposition toward taking personal initiative to influence one's environment" (Li et al., 2010, quoted in Duffy et al., 2016, p. 395). It is associated with job satisfaction, salary and promotions, career success, work motivation, and overall well-being (Fuller & Maler, 2008). A proactive personality may be especially important in buffering the impacts of experiences of marginalization and bolstering individuals' work volition and abilities to adapt. Proactive personality promotes greater resiliency in the face of adversity, increases interpersonal likability, and attracts social support (Duffy et al., 2016).	Youth with proactive personalities will be more likely to overcome the challenges associated with pursuing STEM careers. In the STEM workplace, a proactive personality can help individuals achieve career success, adapt to rapidly changing work environments, and lessen the impact of marginalization. K–12 STEM programs, such as ITEST, which encourage youth to take personal initiative, even in the face of obstacles, can help them develop proactive personalities for success in STEM.

Psychosocial Factor	What is it?	Why is it important?
Work Volition	Work volition is the perceived capacity to make occupational choices despite constraints (Duffy, Diemer, Perry, Laurenz, & Torrey, 2011). It is linked to a range of positive outcomes for both students (e.g., increased career maturity, academic satisfaction, and sense of control) and adults (e.g., increased work meaning, person– environment fit, and job and life satisfaction) (Duffy et al., 2016).	Individuals who believe that they can choose a STEM career are more likely to find and engage in STEM work that is personally meaningful and fulfilling. K–12 experiences supporting STEM work volition help youth persist on a STEM
Career Adaptability	Career adaptability is an individual's readiness and resources for coping with vocational development tasks (Savickas, 2002, p. 156) and includes concern about one's vocational future, perceived control over one's life and personal environment, ***curiosity*** about self and vocational opportunities, and ***confidence*** in one's ability to complete career-related tasks or to overcome obstacles (Savickas & Porfeli, 2012). Given recent, rapid changes in the world of work, the volatility of labor markets, and the need to respond to market demands, such as increasing calls for STEM-trained workers, career adaptability is an increasingly vital attribute.	ITEST's focus on developing foundational STEM skills and knowledge, using professional tools and approaches, and providing opportunities to work hand in hand with STEM professional and technical workers increases opportunities for students to learn about and experience the "realities" of the changing STEM workplace. As students are encouraged to take responsibility for and lead STEM projects and to solve problems, they build confidence in their abilities to complete work tasks and overcome obstacles.
Critical Consciousness	Critical consciousness is a critical understanding of the social and material conditions of oppression and the subsequent informed action taken to transform those conditions (Watts, Diemer, & Voight, 2011). The goal of developing critical consciousness (Freire, 1973) is to address and combat the impacts of inequality and social disparity.	Critical consciousness is known to increase motivation. Furthermore, youth with a sense of critical consciousness will grow up taking action against being marginalized and will seek to change those conditions. K–12 STEM programs such as ITEST provide students with opportunities to develop, early on, strategies to navigate barriers and overcome obstacles to accessing and succeeding in STEM careers. ITEST projects that build youth's self-efficacy as future STEM professionals and support their development of proactive personalities help youth persist in pathways to STEM careers and, once employed in STEM workplaces, overcome barriers and constraints toward upward mobility.

Young people today are growing up in a time of uncertainty and rapid change in the world of work, and this uncertainty can undermine motivation and sense of direction. By addressing these psychosocial factors through both STEM content and guided STEM career-development activities, ITEST helps youth develop the tools they will need to access and persist on the STEM career path of their choosing.

ITEST's Role in Preparing Today's Youth to Meet the Challenges of Work at the Human-Technology Frontier

A variety of NSF programs help students develop the skills and credentials needed to transition successfully to this new work environment. As mentioned earlier, one program in particular that is working to build foundational skills at the K–12 level is NSF's ITEST program. The NSF ITEST program, established by the NSF in 2003 to address the looming shortage of technology workers in the United States, provides rich exemplars of projects that support the factors affecting career development listed above while building the skills needed for citizens to succeed in a science- and technology-driven world of work. ITEST's diverse pipeline of students represents our nation's future scientists, engineers, technologists, and technicians who will increase our ability to discover, create, and innovate at the Human-Technology Frontier. Support provided by the NSF helps students experience what it is like to "be" STEM professional and technical workers, building their self-efficacy as future scientists, engineers, technologists, technicians, and mathematicians innovating and making transformative discoveries in STEM. Working hand in hand with active STEM professionals, young people ages 5–18 use sophisticated technologies to explore their environments, conduct research, build programmable machines, and create

media in schools during the school day and in community settings after school and during the summer. Across ITEST projects, youth use the same technologies, tools, and methods that scientists use on the job. As we have seen in the sections above, the skills, knowledge, and dispositions developed by youth and nurtured in K–12 classrooms largely determine our future STEM workforce. ITEST projects contribute to youth's abilities to build the skills and competencies that will allow them to participate fully in the world of work through the following experiences:

- Using real-world STEM tools and procedures to understand how information and engineering technologies are used to conduct routine tasks and solve problems in scientific laboratories and workplaces
- Developing the foundational concepts and skills in mathematics, science, technology, and engineering needed for STEM careers, which increase students' access to higher level STEM education options and career opportunities
- Interacting with scientists, engineers, technologists, and other STEM professionals who visit classrooms, help students conduct field studies, and serve as mentors to students as they work on real-world problems
- Providing professional learning experiences for teachers that enable them to build the STEM competencies of their students

ITEST Community Addresses STEM Workforce Education Challenges

The ITEST community comprises researchers and practitioners concerned with STEM workforce education. Participation in the ITEST community of practice has provided opportunities for ITEST principal investigators (PIs) to raise and answer questions more far reaching than their individual project work. Over time, collectively, ITEST PIs have worked together to answer some of the bigger questions facing the STEM workforce education community:

- Has the ITEST program evolved a model of successful K–12 STEM workforce education, and, if so, what does that model look like?
- What data should ITEST and other STEM workforce education projects be collecting to demonstrate that individuals are making progress along pathways to STEM and STEM-enabled careers?

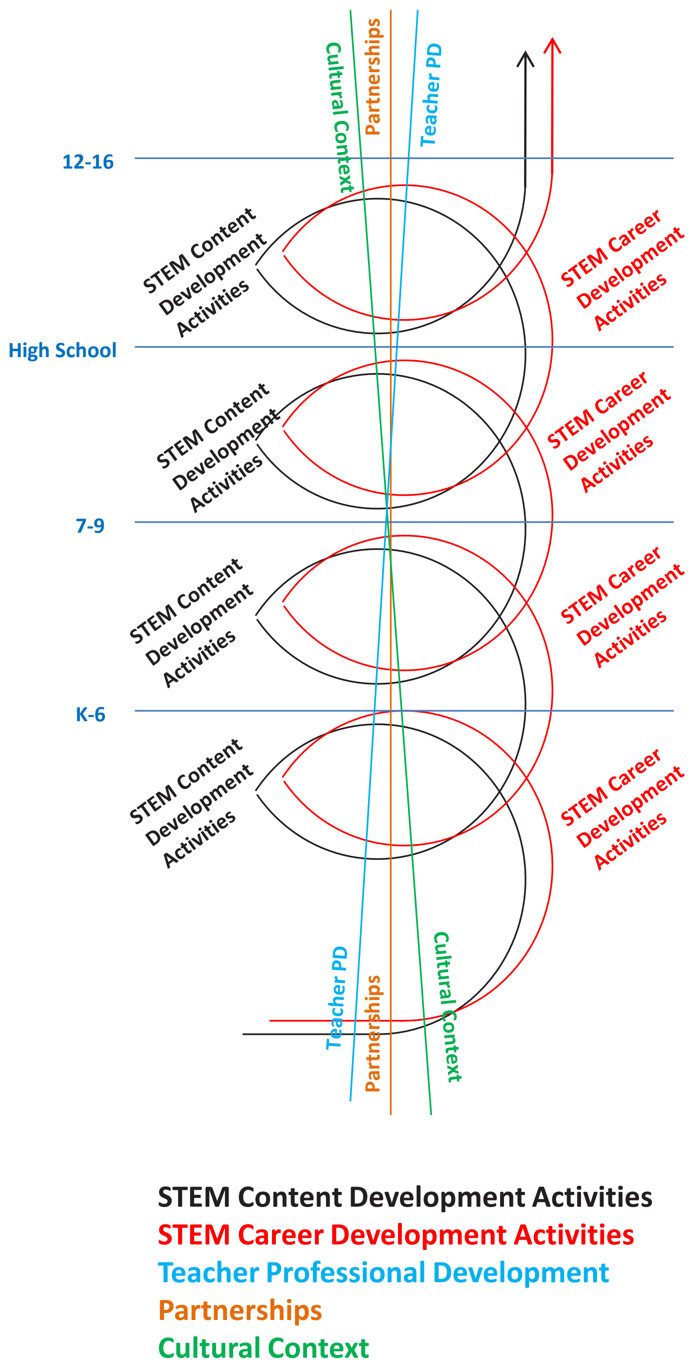
Since ITEST's inception, working groups have helped to explain ITEST's foundational role in STEM workforce education.

In 2011, ITEST PIs and evaluators determined that ITEST youth were developing CT skills, which led to the development of a detailed model explaining students' progression from digital literacy to computer science as they use, modify, and create technologies (Lee et al., 2011). In 2012, ITEST PIs and evaluators determined that a model for engineering education was evolving from the ITEST experience, so they identified those shared model components and intended outcomes (Education Development Center [EDC], 2012). Since then, two working groups—the STEM Workforce Education Working Group and the Data Working Group—have examined, explained, and visualized ITEST's contributions to STEM workforce development. The products resulting from both groups help define ITEST's role in STEM workforce development and explain how ITEST develops the capacities of today's youth to succeed in tomorrow's high-tech STEM workplace.

ITEST's STEM Workforce Education Helix: In 2010, ITEST PIs and evaluators formed the STEM Workforce Education Working Group to determine if a model for foundational STEM workforce education was emerging from the collective ITEST experience that would illustrate ITEST's role in STEM workforce education and add to current research on STEM career development. Reflecting on the current literature on workforce education models and career development, and on a review of intended outcomes of ITEST projects, the working group examined the ITEST portfolio and proposed that ITEST's STEM workforce education support could be optimally understood in the form of a helix. This helix includes five elements: STEM content activities, STEM career activities, public/private partnerships, teacher professional development, and the school's cultural context.

After careful study of how these five elements interact within ITEST projects and appear in literature in the field, the working group concluded that STEM content activities and STEM career activities were two distinct capacities developed by students. Both capacities begin in the early grades and, building on each other iteratively, continue developing throughout students' educational experiences. Their exploration of the ITEST experience led the working group to further conclude that these activities are influenced by school culture and are purposefully supported by schools through partnerships and ongoing teacher professional development (Reider, Knestis, & Malyn-Smith, 2016). The helix below is a useful tool to explain ITEST's role in supporting foundations of STEM career development.

ITEST STEM Workforce Education Helix



ITEST's STEM Workforce Education Outcomes Model: Formed during the 2012 ITEST Summit, ITEST's Data Working Group took the next steps in describing ITEST's role in developing foundational skills for STEM workforce development. ITEST PIs and evaluators in the working group built on prior work to explore what types of data that ITEST projects were collecting as they measured the degree to which their students were showing progress along pathways to STEM and STEM-enabled careers. The review revealed that ITEST projects were collecting data on four categories of outcomes: dispositions, knowledge, skills, and actions taken by youth through their engagement in STEM content activities and in STEM career activities. Furthermore, the group reviewed the ITEST portfolio and provided examples of the types of data they believed should be collected by ITEST and other programs engaging individuals on pathways to STEM careers.

These examples illustrate the types of STEM content and STEM career activities supported by the ITEST program that help youth develop their capacities to succeed in the workplace of the future. These activities also illustrate the ways in which ITEST addresses the career development factors, listed above, that are important to the healthy career development of youth. As shown in Table 2, the ITEST STEM Workforce Education Outcomes Model includes a "theory of action" for each of the outcome categories and examples of constructs that fall within each of the categories. These constructs and examples are well aligned with the factors listed above, illustrating the ways in which ITEST is developing foundational skills needed for success in STEM careers.

ITEST STEM Workforce Education Outcomes Model

Desired Outcomes:

- Employment in STEM Career
- Employment in STEM-enabled Career

Table 2. ITEST STEM Workforce Education Outcomes Model

Categories				
Theories of Action and Examples of Indicators	**Dispositions:** Participation in ITEST projects leads to positive dispositions to STEM content and careers (STEM self-efficacy, interest, engagement, motivation, intentionality, agency, identity, resiliency, aspirations).	**Knowledge:** Participation in ITEST projects leads to increased STEM knowledge and STEM career knowledge (science, technology, engineering, and mathematics).	**Skills:** Participation in ITEST projects leads to increased STEM skills and STEM career skills (application of science, technology, engineering, and mathematics content and related tools).	**Actions:** Participation in ITEST projects, through accumulation of positive dispositions and increased knowledge and skills, leads to actions that increase likelihood students will pursue STEM and STEM-enabled careers (pursuit of in- and out-of-school time STEM activities, persisting in STEM learning).
STEM Content Outcomes (Examples)	"Despite the lack of role models who look like me, I believe I'm good at science" (increased STEM content self-efficacy). "I want to analyze population data" (increased STEM content interest).	Understands the relationship between DNA structure and function (science). Knows the quadratic equation (math). Knows the if, then, else statement (technology).	Uses probeware to collect temperature differences in the soil (science and technology). Applies the iterative process of engineering design (engineering).	Enrolls in higher level STEM electives (persistence in STEM learning). Goes to science museum (pursuit of out-of-school-time STEM activities). Participates in math competitions (pursuit of out-of-school-time STEM activities).
STEM Career Outcomes	"I believe I can be a geneticist" (increased STEM career self-efficacy). "I want to be a statistician more now than I did when the project began" (increased STEM career interest). "There are career opportunities for me as a woman in computer science" (identity).	Knows seismologists study earthquake data to determine the shifting pattern of tectonic plates (science, technology, mathematics). Is aware of required courses and skills for cybersecurity careers (technology, engineering).	Proposes uses for vacant lots in their neighborhood after collecting site data using urban planning tools (tech tools used by scientists to solve problems). Develops an app to teach math to children (technology, engineering, mathematics).	Seeks volunteer, internship, and /or work-based STEM career experiences (pursuit of out-of-school-time STEM activities and persistence in STEM learning). Prepares a STEM career portfolio (persistence in STEM learning).

The literature on career development makes it clear that STEM career development is an iterative process and that STEM dispositions, knowledge, skills, and actions build on each other in nonlinear and recursive ways as youth move along pathways toward STEM careers. Through the two models above, ITEST's working groups on STEM workforce education and data described this process in the collective experience of ITEST projects. As reflected in our review, considerable research evidence establishes the importance of career development interventions in supporting the development of STEM interests and in enhancing student engagement in their academic tasks (Blustein, Kenny, & Kozan, 2014; Kenny, 2013). The ITEST program helps youth develop the foundational STEM skills, knowledge, and dispositions they will carry forward into the changing world of work.

Policy Levers for the Development of a Robust STEM Workforce

This is a turning point for our society and its workforce: a new revolution is on its way. As we look to the horizon of the world of work and its implications for future generations of workers, we have identified a set of key policy levers that can greatly contribute to the development of a robust future STEM workforce, help ensure the well-being of that workforce, and support and sustain a strong innovation economy for our country. As stated earlier, we believe that perhaps the most critical lever is the intentional use of public and private foundation funds to help steer scholarship, educational policy, and workforce development initiatives in directions that will support systematic responses to automation that value work as a core psychological need and human right.

- **Invest in early STEM learning:** To move the needle forward, a greater emphasis is needed on STEM career development programs, such as ITEST, that start in pre-K–12 classrooms. These programs must provide STEM experiences and adequate resources to address early the potential inequalities that restrict participation in STEM careers (e.g., Stanton, Goldsmith, Adrion, Dunton, Hendrickson, Peterfreund, & Zinth, 2017), nurture students' dispositions (e.g., diligence, persistence, cooperation), and develop their interests in STEM, thereby, motivating them to explore STEM career trajectories leading to success in work at the Human-Technology Frontier. In addition, more work needs to be done to advance knowledge of how to implement programs that build on the successes and best practices of programs like ITEST. Significant opportunity exists to deepen understanding of the factors affecting STEM career development and to identify strategies to reduce the impact of gender-based and race-based socialization, which affects students' choices of classes and long-term career plans. To ensure that all students have access to the resources needed to prepare them for success in a future-ready workforce, we need to intervene very early, during the formative years (pre-middle school), when youth develop the foundational knowledge, skills, and dispositions they will carry forward into the workplace.

- **Act now to ensure social stability in the machine age:** To broaden participation in STEM and build a future-ready workforce, more research and dialogue among policymakers, education and workforce development specialists, researchers as well as technical and social scientists from both the public and private sectors are needed to develop programs, approaches, and strategies that address social stability challenges associated with advances in automation at the Human-Technology Frontier. Leaders need to work together to examine and proactively address the issue of access to decent work, as well as the contextual factors and challenges in obtaining careers at the Human-Technology Frontier: economic constraints in early childhood, marginalization, and multiple social identities of individuals who make up the workforce.

- **Carefully consider the ethical, safety, and security implications of the Human-Technology Frontier:** As emerging technologies move toward broader deployment, technologists, researchers, policymakers, and ethicists have raised concerns about unintended consequences of widespread adoption of these technologies. Federal agencies and departments, private foundations supporting workforce and educational innovations, and business leaders have several potential roles to play in this regard. They can convene conversations about important issues and provide the fodder for informed, public discourse on these topics. They can monitor the safety and fairness of applications and contribute to the development and adaptation of regulatory frameworks that encourage innovation while protecting the public. They can encourage the development of policy tools to ensure technologies being developed with federal, or for that matter any, funding increase productivity while avoiding negative economic consequences for certain segments of the workforce. They can invest in the development of ethics-related curricula and professional development for students and practitioners in K–12 and in academia. Finally, they can support the work of researchers and developers to ensure that technological systems are governable; that they are open, transparent, and understandable; that they can work effectively with people; and that their operation will remain consistent with human values and aspirations.

- **Engage research and practice leaders within federal agencies and institutions to engineer innovation and conduct research in STEM workforce education:** To spread quickly and scale successful workforce education for the Human-Technology Frontier, it is imperative to involve those on the cutting-edge of shaping K–20 STEM education with those creating scientific and technical innovations through our nation's research initiatives. Together, these interdisciplinary teams can create breakthroughs in thinking that will dramatically affect designs of STEM workforce education for success at the Human-Technology Frontier. As a body, these teams of thought leaders can bring extraordinary insight and expertise to address the career and workforce development issues raised in this paper, including the effects of scientific discovery and automation; ethical implications; and the importance of developing the foundational knowledge, skills, and dispositions early at the K–12 levels. For example, bringing PIs together across current NSF portfolios—intentionally strengthening the connections among the NSF's K–20 education programs and its research programs—will create a "brain trust" to address what it takes to prepare for success at work at the Human-Technology Frontier, as well as maximize the agency's investments across portfolios. Building on this type of synergy, we strongly advocate that federal agencies and private foundations fund applied and theory-building research that can identify the individual and contextual factors that may support people and communities as they grapple with a society undergoing a radically shifting occupational context.

- **Share findings broadly to leverage change:** The advances from programs such as ITEST and other similar initiatives need to be disseminated to the broader science education and career development communities so that evidence-based best practices can be utilized to improve STEM workforce education experiences for all. This includes sharing advances with a broad, inclusive set of STEM workforce education stakeholders, which begins with the public at-large and includes K–12 education, business, and industry leaders, as well as those engaged in preparing STEM and STEM-enabled workers in career and technical education programs, community colleges, trade schools, and trade displaced worker programs. For example, our team at EDC and Boston College produced a special issue of the *Journal of Science Education and Technology* that described exemplary ITEST projects and highlighted implications for broader educational and career development programming for educators, researchers, workforce developers, and the field. We encourage others to share their findings in similar ways to provide a strong foundation for future innovations.

Conclusion

We believe that the STEM community, workforce development leaders, and government agencies and foundations serving the public good need to be part of the solution by intentionally facing the growing crisis in access to stable and decent work at the Human-Technology Frontier. Informed by research and thought leaders in the field, we have described best current thinking on what work will look like at the Human-Technology Frontier and the types of skills, knowledge, and dispositions that people will need to create and innovate in future workplaces. We have reviewed research on career development and current thinking on the social implications and complex challenges facing work at the Human-Technology Frontier, as well as research supporting the importance of developing strong foundations for STEM careers in pre-K–12 education. We have also described the unique strengths of the NSF ITEST program as a model and mechanism to nurture a future-ready workforce.

The time is right for thoughtful deliberations about the optimal use of federal policy and national funding levers as drivers of adaptive change in the workforce challenges that face our nation. The Human-Technology Frontier holds the promise of great economic growth and social progress, if industry, the federal government, and the public work collaboratively and give careful thought to both the potential gains and the risks that are emerging at that Frontier. By intentionally and systematically investing resources in understanding and intervening in the changes occurring at the intersection of human workers and technology, we are confident that our national institutions can play a major role in creating an inclusive pathway for our youth to find meaning, purpose, and sustained livelihoods in their adult work lives. Forward progress, however, requires action.

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