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DEVELOPING FUTURE SPACE WORKERS: LEADERSHIP NEEDED TODAY

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Summary

The U.S. space industrial base provides hundreds of thousands of jobs, spurs innovation, and is a catalyst for high technology economic growth. But a prerequisite for a strong space industrial base is consistent public and private investment in quality education, especially education in science, technology, engineering, and mathematics (STEM), which benefits society writ large.[1] Decisionmakers interested in the health of the U.S. space industrial base should cultivate a robust, diverse, and multi-faceted space industrial base workforce, from early education to higher education to continuous training. Decisionmakers interested in the health of the broader U.S. economy should also view investment in the space workforce as a key opportunity to create energy and enthusiasm for education in fields of general applicability to U.S. economic prosperity and competitiveness.

While industry and government leaders in the space sector regularly talk about the importance of education and workforce development, consistent investment at scale is still needed. Indeed, the "STEM crisis" in the United States has been discussed as a national security concern within the defense, cybersecurity, and research and development (R&D) sectors, broadly speaking.[2] Creative new approaches that bring together government, industry, and the education sectors are key to the health of the space workforce in the long term.

This paper discusses the critical need for continued public-private partnerships and investment in space-related STEM education; the need for leaders from all space sectors to champion STEM education while expanding and diversifying opportunities; the role of non-degree, non-STEM training in the space sector; and the need for a truly national strategy that includes a centralized index of space-specific STEM education initiatives. Leaders must think now about tomorrow's U.S. space workforce. Strategic investments in STEM education today will lead to a stronger space workforce 25 years from now.

"If you want the [space] workforce of the future…the focus on [STEM] has to start in elementary school, not in high school, not in college…We need to get good policies in place now so that 25 years from now we have the right folks with the right skill sets."

—U.S. Representative Michael Waltz[3]

Introduction

U.S. leaders recognized the national importance of a federal focus on science and math education as early as 1944.* Ever since, national leaders have understood the importance of STEM subjects for nurturing the advanced technical skills needed for a modern, technological-based economy.† Space sector leaders have naturally shared this view. And it must be recognized that the space workforce is a subset of the STEM workforce, therefore preparing the future space workforce requires an analysis and focus on STEM education broadly.

The 2010 National Space Policy outlined goals to foster the development and retention of space workforce professionals calling for innovation, opportunities, partnerships, and investments.[4] More recently, the National Space Council's 2020 "New Era" document calls for removing barriers, creating incentives, and attracting top talent; it also emphasizes the importance of meaningful work and opportunities.[5] And finally the 2020 National Space Policy pushes for targeted investment, a variety of partnerships, and a focus on key enabling disciplines for the space workforce.[6]

The U.S. space workforce includes workers in the civil, commercial, and national security space sectors. One narrowly scoped estimate finds there were more than 183,000 workers in the U.S. space

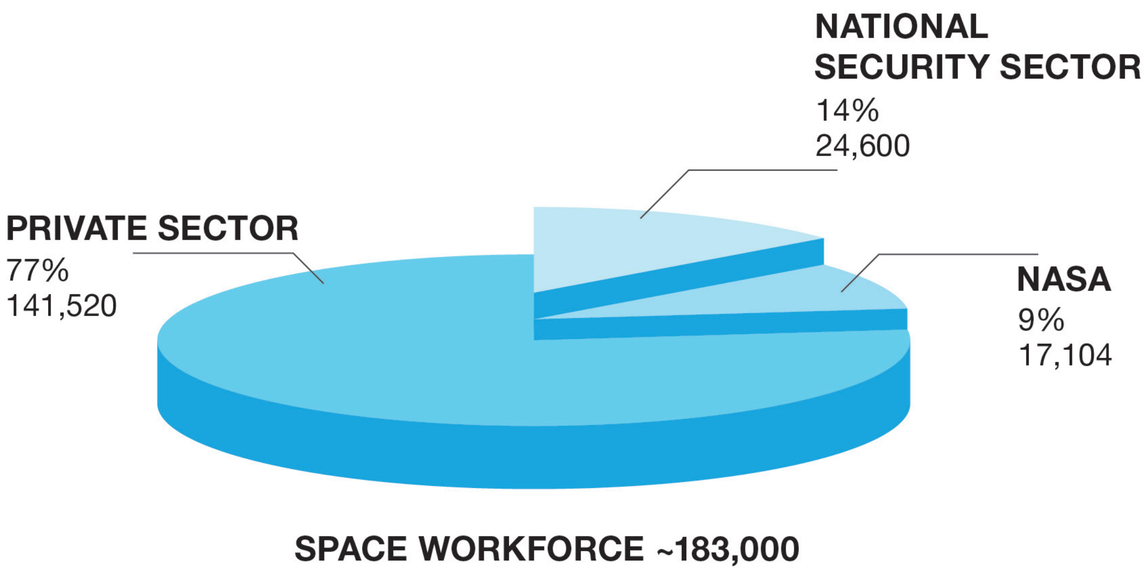

Figure 1: Breakdown of the space workforce according to Q1 – The Space Report 2020.

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*In November 1944, a few months after the passage of the "GI Bill" President Roosevelt posed the following question to the director of the Office of Scientific Research and Development. "Can an effective program be proposed for discovering and developing scientific talent in American youth so that the continuing future of scientific research in this country may be assured on a level comparable to what has been done during the war?" U.S. Government Printing Office, Science, the Endless Frontier, A Report to the President by Vannevar Bush, July 1945. (https://www.nsf.gov/od/lpa/nsf50/vbush1945.htm)

†The term *STEM* and its variations have been discussed for decades, including by the National Science Foundation as early as 2001 and by the U.S. National Academies of Sciences, Engineering, and Medicine in 2005 in a report to Congress on enhancing U.S. competition across the science and technology enterprise. Among many other federal projects, both the national *Educate to Innovate* initiative in 2009 and the five-year strategy for STEM education in 2018 focused on improving STEM education by expanding STEM literacy, diversity and inclusion, partnerships, authentic learning, and transdisciplinary approaches.

workforce as of 2019[7] with a large majority employed in the private sector, though many work on space capabilities being bought by the government. Within the narrow boundaries of this estimate, the largest growth areas are in space vehicle manufacturing, propulsion unit production, and guided missiles.

Space industrial base analysts find it difficult to define and measure the number of space workers since Bureau of Labor Statistics categories do not perfectly align with work in the space sector. The space workforce includes scientists and engineers engaged in *upstream* space industrial base activities, often associated with prime contractors. Job activities here range from research, development, and testing, to launch vehicle, spacecraft, subsystem, and sensor manufacturing. In contrast, *downstream* space workforce activities are often associated with operations personnel and space services providers. For example, some satellite telecommunications and satellite remote sensing company employees may operate the satellites while others work in development, production, and sales of space services and user equipment.[8] When these jobs are added to the narrow estimate above, tens of thousands of more people can be included in the space workforce. These disparate activities rely on workers with either basic or advanced STEM skills.

But competition for skilled workers is fierce. Workers with STEM knowledge and skills continue to be in high demand. The U.S. space enterprise can count on enduring competition for these skilled workers within the space sector, across other U.S. technological industries and internationally. Decisionmakers interested in developing and retaining a robust U.S. space workforce must consider how to sustain consistent public and private investment in STEM education and training for workers involved in upstream and downstream space activities.[‡] In addition, they must consider ways to better publicly highlight exciting and rewarding career paths available to members of the space workforce.

U.S. leaders have many paths they can take to encourage a strong space workforce, including innovative models for partnering with industry and nonprofits, expanding the candidate pool, expanding vocational training opportunities for the space workforce, and investing in the development of a national strategy that considers the vast array of current and future STEM education initiatives.

Partnering to Educate

U.S. space workforce education and training concerns amount to an "all-hands-on-deck" moment. The 2009 *Educate to Innovate* initiative approached the issue with this attitude, securing $1 billion in private investment for STEM education and building CEO-led supporting coalitions across corporate America.[9] As well, in response to the 2010 National Space Policy, many states and companies responded with initiatives to encourage more STEM students and investments. Results have been impressive. As of 2018 there were 243 STEM-related networks at various levels across the United States, which were funded by federal grants, private

[‡]There has been some debate as to whether the United States has been experiencing a STEM "crisis," or not. Analyzing the issue is complex. There is a sense of urgency as the United States continues to fall behind other countries in percentage of highly skilled workers prepared to fill knowledge jobs that drive the American economy (https://www.apmreports.org/episode/2019/01/28/american-graduation-initiative-population-with-degrees). However, measuring the crisis can be skewed when many people with STEM bachelor's degrees do not follow on to STEM careers, and when supply and demand in the job market may result in underemployment or diversion to other career fields. In addition, the space sector continues to grow rapidly, which creates a self-perpetuating cycle of never having enough qualified candidates ready for the workforce (https://www.thespacereport.org/wp-content/uploads/2020/03/emerging_jobs_tsrq319.pdf).

donations, and the business community.[10] And the 2020 National Space Policy has followed on with a call for targeted investments and public-private partnerships within space and technology industries.[11] But U.S. space sector demand is driving the need for even more creative initiatives and sources of funding. In order to develop the space workforce, STEM education must continue to expand and mature to meet the challenge.

The Advantages of Partnering

K–12 school systems across the U.S. have limited and unequal resources, and, while this disparity should be addressed directly, there is also tremendous opportunity for private investment to fill the gap in STEM educational opportunities.[§] Partnerships engage students and supplement classroom learning. Private financial investments are also important in overcoming resource shortages, supplementing curriculums, targeting underserved student populations, enabling additional fields of study, and introducing students to key players in the space sector.

Many STEM education leaders agree that students need hands-on, contextual experiences to inspire and engage them so they will continue to a career in a STEM field. Not only does "real science" inspire and hold student interest, it also builds on current education trends toward authentic, transdisciplinary learning that replaces the antiquated rote learning and "teach for the test" mentality.[**]

Authentic learning can solidify the learning process and may even increase success in "hard" academic subjects by teaching skills for innovative thinking, inquiry, transdisciplinary approaches, and working on integrated, diverse teams—skills that all transfer from school to the workplace.[12]

K–12 and universities that partner with the private and nonprofit sectors generate greater opportunities for meaningful, real-world activities. This is especially exciting in an era of increased human spaceflight, increasingly lower cost small satellites, and the exponential growth in innovative technologies being developed by the commercial space industry. Space sector leaders concerned with the competition for highly skilled workers could attract more talent and an interest in space jobs by exploring more opportunities to partner with K–12 school systems in support of authentic learning experiences starting early on.

"Content without purpose is only trivia!"

— Steve Revington
30+ Year Teacher and
"Authentic Learning" Leader

Bipartisan interest in authentic learning partnerships is evident in the 21st Century Space Grant Modernization Act of 2019, a bill considered by Congress to provide more hands-on research, training, and education programs through NASA.[13]

[§]Certainly, the role of partnerships is important for higher education as well. There are numerous STEM subject university departments that have special relationships with the private space sector. However, attrition rates begin to rise well before students reach university. For this reason, K–12 is more the focus of this section.

[**]Transdisciplinary learning is "an approach to curriculum integration which dissolves the boundaries between the conventional disciplines and organizes teaching and learning around the construction of meaning in the context of real-world problems or themes." Basically, it integrates expertise and experience from multiple disciplines for a more holistic approach to a subject and reflects real-world problems to deepen learning and understanding. United Nations Educational, Scientific and Cultural Organization, International Bureau of Education (http://www.ibe.unesco.org/en/glossary-curriculum-terminology/t/transdisciplinary-approach).

Another bipartisan bill, the Minority Serving Institution (MSI) STEM Achievement Act introduced in 2019 called on federal science agencies and the Office of Science and Technology Policy to undertake activities to improve undergraduate STEM education and enhance research opportunities.[14] However, both of these bipartisan bills stalled in Congress and were never passed.[15]

Out-of-school programs are also especially important to the learning process, especially in K–12.[16] STEM classroom teachers need "academic partners," particularly outside the regular curriculum, to increase after-school and out-of-school programs. For example, AmeriCorps's 2017 partnership with the commercial company FIRST Robotics targeted $1.4 million for providing national service volunteer STEM teachers to low-performing schools.[17] Many such programs also take the form of "citizen science" beyond the classroom initiatives, where learners of all ages participate in science in a real-world context, deepening learning and encouraging students to establish ambitious goals.[18]

Universities and nonprofits also partner with K–12 schools to develop curriculums and out-of-school programs, support professional learning of teachers, and introduce STEM and space sector jobs to underrepresented students.[19,20] Indeed, there are many private enterprises and nonprofit organizations with community outreach programs concentrating on space-oriented STEM that work to fill gaps in professional development for teachers and gaps in student educational opportunities, including mentorship programs.[21]

Leaders should raise awareness of these opportunities and make the case for additional investment. Encouragement and investment from the private space industry and nonprofits in authentic and extracurricular STEM learning, coupled with national, state, and local education policies that overhaul antiquated methods and incentivize partnerships, would serve to deepen STEM learning and better prepare students to go from classroom to workplace. Moreover, space workforce advocates, space industry leaders, and governmental affairs representatives should be aware of bipartisan proposals for STEM-supporting legislation in Congress, such as the 21st Century Space Grant Modernization Act of 2019 and the MSI STEM Achievement Act, so that their views on the legislation are heard in Congress.

While both authentic learning and supplemental learning opportunities can help guide today's students into tomorrow's space careers, partnerships can also be purely financial at all levels of education. Private financial investment in scholarships, grants, loans, and even privately funded summer camps or robotics teams offer many possibilities.[††] Additional options include paid internships, research partnerships with universities, and professional development opportunities for teachers. U.S. space workforce demand drives the need at the national, state, and local levels for financial investments in all levels of STEM education, from early education to continuing adult education. Private investment will

[††]There are a number of initiatives oriented toward space that have creative solutions to stimulate and support STEM education. One example new in 2020 is the association-sponsored Zed Factor Fellowship for higher education students from underrepresented communities. A second example is the nonprofit Space Foundation's Center for Innovation and Education that targets supplemental education for all ages, training and content for teachers, and networking and mentorship for young and midcareer professionals. The Air Force Association's StellarXplorers space system design competition for high school students nationwide is yet another example. Each of these programs relies on outside sponsors from across the space enterprise and attempts to target STEM education, thus the future U.S. space workforce, from a different angle.

be needed to ensure the U.S. space workforce in the near-term and long-term has the technical skills and knowledge to remain globally competitive.

However, financial supplements to the U.S. education system should not come only from outside the government. A 2020 White House progress report on the STEM strategic plan identified 174 federal agency programs with over $3.6 billion budgeted for FY20.[22] A specific example for space is NASA's STEM Engagement Program that spent $110 million in 2019 on education programs through internships, grants, partnerships and teacher opportunities.[23] The government brings a scale of investment difficult for private enterprise and nonprofits to match.

Fostering Partnerships Through Policy

Decisionmakers should be forward thinking when making the difficult decisions and fiscal trades necessary to balance near- and far-term needs. National, state, and local governments, with the support of corporate leaders should create policies that incentivize private investment broadly across STEM education, from authentic learning programs and supplemental learning opportunities to simple financial contributions.

Decisionmakers should consider policies that incentivize use of modern STEM curriculums and methods of teaching. For example, with the help of private sector partners, leaders could incentivize local governments, school boards, and educators to modernize their teaching methods with a reward system that highlights their schools' contributions to high tech or space workforce education. Government leaders could offer incentives such as tax rebates to space companies that partner with learning institutions. To foster investment in targeted key enabling disciplines, leaders across the government and commercial sectors could build corporate-public coalitions to address shortfalls in a specific depressed regional area or in a specific area of study or STEM skill.

State and local primary and secondary education authorities could create one or more permanent positions to directly interact with local private space companies and nearby universities to develop tailored learning programs specific to areas of interest. A dedicated outreach office in every school district would bring together students, faculty, local industry, and higher education institutions. Local industry would have the opportunity to invest in potential future employees and shape the development of the skills they anticipate needing. Faculty and students would be provided supplements to classroom learning and required curriculums. Programs could center around a specific age group, an anticipated key enabling skill or emerging technology, an underrepresented demographic in the space workforce, or a depressed geographic region. Perhaps one way forward would be for K–12 school systems with existing dedicated technology departments to expand the mission of those departments to include partnerships such as this. Space sector leaders could encourage school systems to undertake such expansion and provide support.

Measuring Impact

Of course, any type of incentivizing and partnering should be measured for success periodically using hard data. There should be a continuous evaluation of what works and what does not work. Developing and managing a standardized measure of achievement that quantifies the return-on-investment for the space sector will lead to accountability and allow for course corrections in planning a national space workforce. Workforce analysts need to do more research into how to holistically measure success in this area.

Expanding the Candidate Pool

Studies confirm that having a diverse team improves decisionmaking and innovation and increases overall performance—all aspects of a successful space enterprise.[24] In order to improve overall performance and maintain excellence of the future space workforce, leaders must commit to diversifying the candidate pool through diversifying STEM education. As one commercial space services provider put it, there is a need to support diversity initiatives "through the academic pipeline to a successful early career placement."[25]

Disparities in the number of STEM-oriented students found across regions in terms of economic status, gender, and race have long limited the STEM-educated talent pool from which employers choose. National leaders must give greater national attention to correcting this disparity and expanding STEM learning. It is critical to U.S. leadership in space.

The unpassed MSI STEM Achievement Act previously mentioned stated, "[t]he composition of the STEM workforce does not reflect the current or projected diversity of the Nation, with Hispanics, African Americans, and other racial and ethnic minorities significantly underrepresented in the STEM workforce compared to their presence in the workforce more generally."[26] Since the space workforce is a subset of the STEM workforce, analysis of the latter is informative. Table 1 shows specifically the aerospace defense workforce as predominantly white and male.

Table 1: Aerospace/Defense Workforce Diversity, 2018*

Demographic	Percent of Employees
Female	24.0%
Black	6.8%
Hispanic	7.6%
Asian-American	10.0%

*Source: Q1—The Space Report 2019, The Authoritative Guide to Global Space Activity (https://www.thespacereport.org/wp-content/uploads/2020/03/workforce.pdf)

Diverse workplaces employ people of different genders, ages, races, cultural backgrounds, languages, and national origins. Workplace diversity offers the following advantages:

- Expanded creativity and problem solving
- Better decisionmaking
- Increased profitability and productivity
- Enhanced employee engagement and retention
- Improved company reputation

Source: Indeed for Employers

The question is whether current conditions of underrepresentation are due to lack of qualified candidates and/or limiting promotion and hiring practices, or something else. Since STEM education is the underpinning of the candidate pool for the space workforce, one important path to expanding that pool is addressing inequities in education, such as discrimination in the classroom, vast resource disparities among schools, and the scarcity of non-white STEM teachers.[27] There is a significant opportunity for the United States to not only increase the number of students choosing STEM career paths but to diversify the talent pool.

It is crucial to have leadership that commits to diversity goals without which the U.S. space workforce may never reach its true capacity. The space industry depends on growing the pool of STEM talent and, therefore, should be strongly interested in both private and government action to close the gap. Also, it should support relevant legislative proposals at the local, state, and federal government levels.

Closing the Gap on Opportunity

Opportunities in the education pipeline begin to diminish early on for some demographic groups. For example, studies show that an indicator for entering STEM fields is whether or not students take Algebra I in 8th grade, early enough to attain the needed high school-level math that provides the educational basis for engineering, science, and other STEM-related fields.[28] Black, Latino, and low-income students are more likely to attend schools that do not offer Algebra I.[‡‡,29] Leaders need to commit to raising the minimum levels of math offered in each grade across the country as a first step to equal educational opportunity.

Additionally, studies show that a primary driver for those who pursue higher STEM education is the amount of economic, cultural, and social capital they possess. Some researchers have narrowed this concept for STEM to "science capital."[30] Low capital has a direct association with socioeconomic disparities and access to resources in a community.[31] This can affect the opportunities learners have to pursue STEM studies and careers. Not only could space leaders advocate for more equal classroom resources but also resources of entire communities. There needs to be a commitment of resources for examining the structural deficiencies that retard STEM educational opportunities in regions and communities.

In order for the U.S. space workforce to diversify its pool of candidates, leaders at the national, state, and local levels should seek to identify and remove roadblocks to opportunity for underrepresented groups. Doing so will require attending to the entire education pipeline—from early education to the university level.

Closing the Gap on Attrition

In addition to leveling early math opportunities and understanding the role of "science" capital, there is also a need to close the gap on attrition in education.

The Symbiotic "Capital" of Every Learner

Economic capital – an individual's financial assets

Cultural capital – the nonfinancial resources an individual has (ingrained habits, skills, and dispositions that can extend to other resources such as art, food, speech, and clothing)

Social capital – viewed through the lens of economic and cultural capital, relationships that can be mobilized into resources (teachers, peers, and family)

Science capital – measured by science-related qualifications, understanding and knowledge of science and knowing someone who works in a science-related job

Higher rates of any of these affect rates of the others and can mean greater competencies and credentials for an individual and aid economic status, especially through educational opportunities and over generations, to further support equal opportunity.

For STEM subjects, attrition rates are disproportionately higher for women and girls, Black, and Latino students.

Statistics from the U.S. Census Bureau and the Department of Education show there is no shortage of students attracted to STEM degrees; however, a large number of students pivot their focus in the job market, do not pursue advanced degrees, or simply lose interest.[32] Figure 2 shows a comparison from 2019 of how White, Black, and Latino students completed their STEM degree, switched majors, or left college altogether.[33] Additionally, studies show that women account for only about 20 percent of total STEM college graduates, and girls

[‡‡]It should also be noted that suburban students are twice as likely to meet STEM proficiency benchmarks than their urban or rural counterparts. https://www.thespacereport.org/wp-content/uploads/2020/03/education_tsrq319.pdf.

disproportionately start to lose interest in STEM areas as early as middle school.[34]

Observers have raised awareness of these disparities, but more needs to be done. Policymakers should develop strategies and better advocate for increasing STEM education resources to women and girls, Black, Latino, and rural student populations.

As the space economy continues to grow and create more jobs in the workforce, to grow the space workforce pool, space sector leaders should pay attention to and invest in underrepresented, underserved students and their education at universities, technical colleges, secondary schools, primary schools, and community programs. This commitment will lead to more diverse workforce-ready candidates and a stronger overall enterprise labor force.

Expanding Education with Distance

The 2020 COVID-19 pandemic forced rapid implementation of distance-learning techniques at all levels, including in many communities that were not well prepared. The results have been mixed, especially for underserved student populations.[35] However, education leaders can use this experience to hasten development and improve decisions related to the evolution of learning itself.

The rapid growth of distance learning since 2020, and experience gained from the mistakes made, provide an opportunity for expanding the reach of STEM education. Online resources can be crafted to improve educational experiences across the divides of gender, race, income, and location. However, communities with low cultural capital will still need increased support for home learning.

Decisionmakers and leaders in education will need to drive new ideas that exploit existing programs and practices for online, distance learning. They then will need to carry through with the eventual return to in-person classrooms. The community will need continued investment in infrastructure, internet access, and professional training for instructors as well as in development of engaging online content.

Redefine "Space Job" Training

While developing space-specific knowledge and skills benefits the sector, consideration should be given to how all STEM fields are starting to overlap in the space sector with the promise of cislunar development and humans to Mars, for example. Biology, medicine, geoscience, civil engineering,

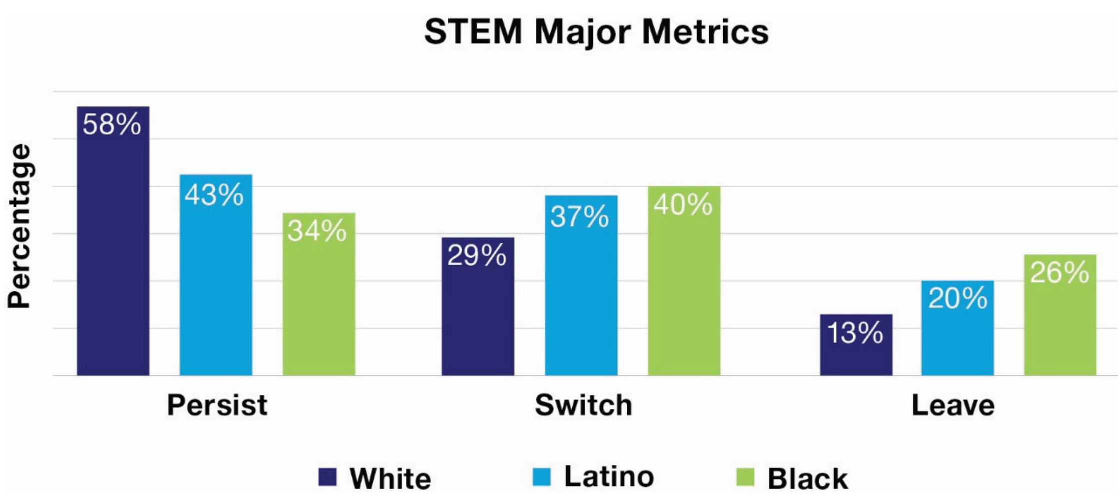

Figure 2: Comparison of how STEM degrees are pursued.

and machine learning all intersect when settling the moon or Mars.

Looking ahead, a career in the space sector will not necessarily mean being a scientist, engineer, mathematician, or software developer. At the same time, many of today's jobs already involve practical technical knowledge; from working on the shop floor to car mechanics, even farmers and fisheries use technology to improve productivity. The transdisciplinary nature of the future of work began decades ago.

The Role of Non-University Education and Training

When considering the development of the space workforce, the space community should not overlook the role of non-university education for both basic and specialized STEM skills that enable key disciplines necessary in the space sector. This is not a new idea. In an earlier era of rapid technological change, the Truman Commission of 1946 established an outline for the community college system.[§§]

There will always be a need for advanced, degree-level knowledge of science, technology, engineering, and math to lead in space activities. However, there are highly specialized skills in the space sector that do not require full advanced STEM degrees. Consider how cybersecurity and satellite assembly play into the U.S. space sector.

Community colleges, the focus of the underfunded 2010 American Graduation Initiative, have lost nearly 20 percent of their enrollment over the past decade[36] as well as significant amounts of local and state funding.[37] However, there are ways community colleges and vocational schools can bolster the space workforce quickly, affordably, and continuously. For example, community colleges and vocational schools play a large role in "skilling up" for high-demand, specialized skills. These institutions could play a significant role in closing skill gaps caused by advancements of game-changing technology. The 2020 National Space Policy calls out many of these from machine learning to geoscience.[***] However, beyond this list, perhaps decisionmakers should develop a "science and technology roadmap" that matches these enabling disciplines to targeted investments that improve the expertise, capacity, and infrastructure at community colleges and vocational schools.

Community colleges and vocational schools will also play a large role in recovery from the 2020 economic downturn. Typically, college enrollment numbers increase as people lose jobs and seek to retrain. Interestingly, this did not happen in fall 2020; perhaps due to continued health and safety concerns from the COVID-19 pandemic, enrollment numbers fell across all higher education sectors.[38] This will probably not last, however. There will be a time when people go back to school and need to

[§§]The Truman Commission emphasized the need for affordable education options and federal investments, establishing what is today the community college system, integrated vocational training, and expanding adult education programs, It was in response to the overwhelming numbers of World War II veterans who needed training and jobs at the cusp of the quickly changing, highly technical atomic age. https://archive.org/stream/in.ernet.dli.2015.89917/2015.89917.Higher-Education-For-American-Democracy-A-Report-Of-The-Presidents-Commission-On-Higher-Education-Vol-I---Vi_djvu.txt.

[***]2020 National Space Policy, Foundational Activities and Capabilities. "Sec 4, 1, (f), vi. Support training and education in key enabling scientific and engineering disciplines, including: artificial intelligence and machine learning, autonomy, orbital mechanics, collision avoidance methods, robotics, computer science and engineering, digital design and engineering, electromagnetics, materials science, hypersonics, geoscience, quantum-related technologies and applications, and cybersecurity." https://trumpwhitehouse.archives.gov/presidential-actions/memorandum-national-space-policy/.

retrain for new careers from job loss in 2020. Economic recovery from the pandemic may take years.

The role of vocational schools and community colleges may take on even greater significance with sustained interest in distance-learning options due to the expansion of online learning infrastructure, experience, and opportunities, as well as students' adaptability and aptitude development for learning online. More research needs to be done to understand the trends in a post-pandemic, more remote-education-accepting world. Nonetheless, non-university institutions will need further investment in their infrastructure and facilities, administrative and information technology (IT) systems, and curriculums in order to adjust to these changes. Non-university education and training can help the U.S. space sector meet workforce requirements and should not be overlooked in space workforce policies, investment, and partnership opportunities.

Cross-Discipline Space Jobs

So far, this discussion has focused on STEM education as an essential element of space workforce development. But the makeup of the national space workforce goes beyond space per se and beyond advanced or specialized STEM knowledge and skills. In fact, having only *basic* knowledge of STEM subjects is the foundation of many careers in space. The pool of candidates evaporates somewhat when advanced STEM degrees are overemphasized.

Not being an engineer or scientist does not preclude someone from entering the space workforce. It is transdisciplinary by definition and practice. In addition, advancements in technology like machine-to-machine learning or easy-to-grasp computer interfaces create a much shorter learning curve and may reduce the requirement for advanced knowledge of complex engineering. A career in space is not necessarily limited to candidates with advanced degrees in traditional STEM fields. For example, the success of a space program depends on a mixture of basic STEM knowledge with other expertise such as advocacy and policymaking. Communications and media experts are needed to grasp and explain engineering and scientific concepts. Accountants and contract specialists are needed to understand complex engineering workplans. A comprehensive, successful space enterprise will need a workforce with knowledge and skills in these and many other areas.

In addition, recruiting and retaining today's young scientists and engineers into the space workforce should force leaders to think about more than the importance of STEM degrees. The hard problems of space require transdisciplinary skills, and soft skills, such as collaboration, adaptability, creativity, and cross-cultural intelligence. Today's young scientists and engineers need to develop these soft skills early, and incumbents in the workplace should continue to develop and maintain these skills. In addition, to better match their life experiences and career expectations, new entry space workforce employees may demand a work environment where teams are agile, autonomous, and egalitarian.

Opening the aperture of how to educate and train the U.S. space workforce with skills beyond STEM will increase opportunities for successful development across the enterprise. This relates directly back to the transdisciplinary approach to learning needed in the U.S. education system. Policies and programs that enable a cross-disciplinary approach to workforce development and education would attract well-rounded candidates and build teams of professionals that are equipped to meet the challenges of space from all sides.

A Truly National Strategy

While STEM education is the foundation of many modern career fields, from the IT to medical sectors, there are considerations unique to the space sector. Developing education and training initiatives that highlight space would serve to pull and hold more graduates in the sector. For example, the nationwide K–12 Next Generation Science Standards and its many curriculum aids that target space may attract younger students to space.[39] Meanwhile, in higher education, a number of research and development programs exist that connect universities to national laboratories and industry, especially at the graduate level. In fact, numerous education-based government and private initiatives, public-private partnerships, and curriculum innovations contribute to building the STEM workforce at a national level, whether space-specific or not. What is not clear is the national plan for ensuring success.

Between the federal government, private industry, nonprofits, and more, so many programs exist that it is hard to track what is available, what is missing, and what is successful. The 2020 National Space Policy called out education as being necessary to ensure mission success, build capabilities, stimulate innovation, and advance innovation and discovery. To build the space workforce, a more detailed *truly national strategy* for space is needed that includes a centralized hub of all the thousands of initiatives already in place that focus on space science. The national strategy also needs to include a measurement of impact for current and future initiatives to give perspective, gauge success, and provide vector checks.

The Committee on STEM Education (CoSTEM), as established by the America COMPETES Reauthorization Act of 2010, is charged with tracking and assessing STEM programs, investments, and activities throughout federal agencies.[40] However, since it is limited to tracking only federal government activities and is not space-specific, it misses the many, many other programs, investments, and activities for a truly national strategy for STEM training and education that focuses on space. A centralized, national-level hub that is voluntary to join but incentivized for broad-based participation would lead to better tracking, better planning, and better allocation of resources. This hub could be managed by government, a national laboratory, a government corporation, or a nonprofit entity. The most important aspect of this hub would be to provide a picture of space-specific STEM education, training, and opportunities across the national landscape that assesses impact and highlights challenges and opportunities.

Conclusion

Leaders across the U.S. space enterprise will need to see space-related STEM education as a shared burden with educators in terms of the investments of time, money, and resources. Sharing the burden should be viewed as vital to the global leadership of the U.S. civil, commercial, and national security space sectors. As discussed above and shown in Table 2, many opportunities exist across government, the private sector, and the K–12 education community to develop the space workforce by fostering relevant STEM education.

Partnerships among the space industry, K–12 schools, and all forms of higher education need to continue to grow in order to engage students with authentic learning to sustain interest in STEM subjects, especially science, throughout the academic pipeline. Space enterprise leaders should encourage policies and legislation that incentivize investment and partnerships in STEM education. In addition, active engagement with young people and educators can raise awareness and introduce the idea of a career in the space sector early on.

Meanwhile, space enterprise leaders should consider how a diversity of approaches and backgrounds in U.S. space efforts increases

Table 2: Multilevel Actions Toward Improving Space Education	
Sector	**Action**
Government	• Local ‣ Foster partnerships among school districts, industry, and higher education institutions. ‣ Ensure schools have resources to offer higher math from middle school to high school. ‣ Ensure equitable distribution of STEM learning resources and opportunities, including online learning. • State ‣ Encourage nongovernment stakeholders to invest in STEM education for space. ‣ Officially adopt STEM curriculums that include transdisciplinary learning. ‣ In locations close to space industry activities, encourage (and, if possible, fund) school districts to establish one or more permanent positions that directly interact with local private space companies and nearby universities to develop tailored learning programs specific to space-related areas of interest. ‣ Prioritize STEM-related infrastructure, opportunities, and course offerings at community colleges and vocational schools. ‣ Offer financial aid programs to underrepresented groups and for key technology-enabling disciplines in space for vocational schools, community colleges, and universities. • Federal ‣ Include diversity enhancement, modernization of infrastructure, and the role of public-private-partnerships in STEM-related legislation. ‣ Develop a nationwide STEM education plan for space that can track government and private programs and measure impact for periodic vector checks. ‣ Facilitate development of a national strategy of space workforce development. ‣ Establish metrics for tracking the progress of space-related education and training programs. ‣ Allow and encourage formulation of private-sector coalitions to stimulate STEM education without violating antitrust laws.
Private	• Create partnerships with school districts and universities for such things as extracurricular learning, work experience, internships, and networking. • Raise awareness and introduce the idea of a career in the space sector early on. • Target underrepresented groups and regions. • Create “science and technology roadmaps” to be used by education planners and lawmakers that identify areas of study to enable key emerging technologies. • Invest financially in nationwide and local K–12 STEM programs and research areas for space. • Lobby Congress for more STEM-focused planning that benefits the space sector.
K-12 Education	• Create a centralized outreach position or office to partner with private industry and universities. • Make programmatic decisions that exploit online learning trends. • Develop curriculums that ensure appropriate higher math is available from middle school through high school to support higher STEM education. • Promote transdisciplinary STEM education K–12 to retain student interest, especially in science and engineering, and authentic real-world learning. • Create partnerships from K–12 schools to universities and to nonprofits that supplement learning opportunities and curriculums space science.

innovation, creativity, and the overall success of the industry and the mission. Diversifying the space workforce pool of candidates will rely on expanding STEM educational opportunities to more Americans. Educational, corporate, nonprofit, and government leaders at all levels must bring greater attention and consistent, sustained investment to close the gaps in opportunity to master foundational maths such as Algebra I, and reduce divergent attrition rates across regions, race, and gender. As well, the opportunities created with the recent explosion of online learning tools should be leveraged to expand the candidate pool.

What's more, many space jobs are not only for workers with advanced degrees in STEM fields. Space jobs can involve highly specialized technical skills that do not need advanced degrees, or they can be transdisciplinary jobs that use basic STEM knowledge to support the space enterprise. Leaders will need to champion investment in vocational and community schools as affordable options during economic recovery and as affordable alternatives that can expand the candidate pool. The development of "science and technology roadmaps" would work to help anticipate future skills gaps and focus training investments on key enabling disciplines.

This is indeed an "all hands on deck" moment. A truly national plan needs to be put in place that envelops all space-enabling STEM education public and private activities in order to make better strategic decisions. Investments in STEM education, K–12 as well as all forms of higher education, will provide for the future U.S. space workforce, but it cannot be done without supportive legislation, policies, strategies, and resources from government at all levels; continued public-private-partnerships; and buy-in from educators. The future of the U.S. space workforce for the next several decades depends on leadership decisions taken in 2021.

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Appendix: Who Are the Space Workforce?

The space workforce ranges from scientists and engineers engaged in *upstream* industrial base activities such as research and development; and launch vehicle, spacecraft, component and sensor manufacturing; as well as *downstream* activities in operations, and development, production, and sales of user applications and equipment. Jobs in the space workforce are not limited to these upstream and downstream functions. A number of cross-disciplinary job types are needed to field and operate U.S. space assets from policy strategists, governmental affairs, and legal experts to budget analysts and public affairs. For these reasons, defining the space workforce has been difficult.[41] Even with expanded STEM education, grooming of early career professionals in these job types tailored toward space may need some deliberate planning.

What's more, many downstream space applications lead to new design requirements upstream, creating a positive, upward spiral for advancement in space capabilities and user applications. U.S. government and industry leaders need to understand this positive feedback loop in order to anticipate future workforce needs.

Upstream

Upstream workers decide what is built, how it is built, and then build it. Some examples include:

- Scientists – physicists, mathematicians, chemists, other basic sciences
- Engineers – mechanical, electrical, materials, structural, civil, aeronautical, computer, chemical, astronautical
- Assembly and production workers and managers with specific skills
- Construction and infrastructure workers
- Software/hardware developers/programmers/testers
- Security – physical security and cybersecurity
- Program managers with technical background and major project management skills
- Supply chain managers

Downstream

Downstream workers operate and use what has been designed and built upstream. Much of today's satellite operations are automated using artificial intelligence and direct communication links; however, the human-in-the-loop aspect of satellite operations may never go away. Though not always specific to space, examples include:

- Antenna/satellite dish technicians
- Satellite ground system maintainers
- Network operators
- Satellite mission controllers
- Operations Center managers
- Software/hardware developers/programmers/testers
- Security – physical security and cybersecurity

Applying what we learn from space on the ground involves familiar applications like handheld GPS devices, Earth data fusion and analytics, telecommunications, and weather modeling applications. A few examples of job types in those sectors are:

- Big data analytics experts
- Programmers, software/hardware
- Supply chain managers
- Consumer/customer interfaces

The U.S. space workforce consists of many skilled workers who can move between the space sector and other sectors depending on their interests and experience. A number of job types are competing between both upstream and downstream such as cybersecurity specialists, program managers, and software developers. The U.S. space workforce also has competing interests across the civil, commercial, national security, and industry sectors. Each has pros and cons in terms of salary, advancement opportunities, job security, hiring requirements, work-life balance, and location, for example.

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