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AI Education in China and the United States

A Comparative Assessment

CSET Issue Brief

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Executive Summary

Many in the national security community are concerned about China's rising dominance in artificial intelligence and AI talent. That makes leading in AI workforce competitiveness critical, which hinges on developing and sustaining the best and brightest AI talent. This includes top-tier computer scientists, software engineers, database architects, and other technical workers that can effectively create, modify, and operate AI-enabled machines and other products.

This issue brief informs the question of strategic advantage in AI talent by comparing efforts to integrate AI education in China and the United States. We consider key differences in system design and oversight, as well as in strategic planning. We then explore implications for maintaining a competitive edge in AI talent. (This report accompanies an introductory brief of both countries' education systems: "Education in China and the United States: A Comparative System Overview.")

Both the United States and China are making progress in integrating AI education into their workforce development systems, but are approaching education goals in different ways. China is using its centralized authority to mandate AI education in its high school curricula and for AI companies to partner with schools and universities to train students. Since 2018, the government also approved 345 universities to offer an AI major, now the country's most popular new major, and at least 34 universities have launched their own AI institutes. The United States is experimenting with AI education curricula and industry partnership initiatives, although in a piecemeal way that varies by state and places a heavier emphasis on computer science education.

Both countries' approaches could result in uneven levels of AI workforce competitiveness, although for similar and different reasons. China's centralized push could lead to widespread integration of AI education, but the resulting curricula could be shoddy for the sake of participating in the "AI gold rush." This risk is especially pronounced in under-resourced areas, which could produce underwhelming results. The United States' varied, decentralized approach may allow for greater experimentation and innovation in how AI curricula are developed and implemented, but diverse approaches may exacerbate disparities in curriculum rigor, student achievement standards, and educator qualifications. As for similarities, the two countries share hurdles such as the rural-urban divide, equitable access to quality AI education, and teacher quality.

Ultimately, this report suggests future U.S. science and technology education policy should be considered in a globally competitive context instead of viewing it exclusively as a domestic challenge. For the United States, that consideration includes recognizing and capitalizing on its enduring advantage in attracting and retaining elite talent, including Chinese nationals. While this brief does not make policy recommendations for the U.S. education system, the upcoming CSET report "U.S. AI Workforce: Policy Recommendations" addresses some of the direct implications of the findings presented.

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Introduction

Much has been written on how the Chinese government recruits foreign artificial intelligence talent. However, little is known about China's ongoing initiatives to build their own AI workforce. Existing scholarship also lacks a detailed examination of how Chinese and U.S. approaches differ when it comes to AI education.

To fill this gap, this issue brief details how both countries are integrating AI education and training into every level of education. It discusses potential national security implications of each country's strengths and weaknesses, and highlights improvement areas for future U.S. science and technology (S&T) education and workforce policy. We aim to provide a clear-eyed assessment of the U.S. approach to AI education as it exists within the country's decentralized education system. A discussion of the strengths and weaknesses of these systemic realities, especially relative to China's system, will help policymakers better address critical barriers to U.S. AI competitiveness.

The research presented in this brief is based on primary source U.S. statistics, reports and assessments from education nonprofits, publicly available information from the private sector, and individual states' departments of education, along with Chinese education plans and policies, official statistics, and translations. The data is often defined and categorized differently, making uniform comparisons difficult. We attempt to clarify such differences when they occur.

Overview of China’s Education System

China’s education system is overall more centralized than its U.S. counterpart. Its education system includes 282 million students in 530,000 educational institutions across all levels. China’s Ministry of Education is the main authority overseeing China’s education system, and is responsible for certifying teachers, setting national education goals, curricula and teaching material, and providing limited funding assistance.[1]

While the MOE supervises provincial education departments, it has granted more implementation responsibility to the provincial and municipal levels over recent decades.[2] Responsibilities at the provincial and major city level include following national guidelines to develop provincial curricula based on developing an implementation plan that incorporates local contexts and MOE national curriculum guidance, then sending the plan to the MOE for approval before implementation.[3] Further local responsibilities include administering teaching materials, school programs, providing education subsidies, and setting additional standards for teacher training.[4]

The MOE establishes goals for its education system through five- to 15-year education strategies. The goals for 2010–2020 include universalizing preschool education; improving nine-year compulsory education; raising senior high school gross enrollment rate to 90 percent (which has already been exceeded); and increasing the higher education gross enrollment rate to 40 percent. Provinces then typically follow to create their own education plans.[5] The MOE’s Bureau of Education Inspections monitors implementation and provides feedback to local governments.[6]

For details on China’s education system, see the accompanying brief “Education in China and the United States: A Comparative System Overview.”

Overview of the United States' Education System

The U.S. education system is more decentralized than its Chinese counterpart, especially for primary and secondary education. Each state's department of education is the authority that determines the laws that finance schools, hire educators, mandate student attendance, and implement curricula. In contrast to China's MOE, the U.S. federal government provides relatively minor education oversight through the compilation and reporting of education statistics, along with promoting equitable access to education and enforcing a prohibition on institutional discrimination.[7]

The U.S. Department of Education, the United States' federal agency for education, proclaims that education is a "state and local responsibility," and the federal government's role in education is more of a "kind of emergency response system" to fill gaps when "critical national needs arise."[8] The most notable federal education initiatives, such as the Elementary and Secondary Education Act of 1965, the No Child Left Behind Act of 2002, and the Every Student Succeeds Act of 2015, reflect the U.S. government's efforts to promote childrens' equal access to quality public education.

At the postsecondary level, the federal government has slightly more authority through its administration of student financial aid. The Department of Education supports programs that provide grants, financial aid (loans), and work-study assistance. Roughly 66 percent of students apply for federal financial assistance.[9] The department's student loan programs have more than 43 million outstanding borrowers, with outstanding student debt now over $1.7 trillion.[10]

The jurisdiction of the U.S. Department of Education is rooted in the U.S. Constitution. As a result of the division in constitutional authority, states develop curriculum guidelines and performance standards, license private elementary and secondary schools to operate within their jurisdictions, certify teachers and administrators, administer statewide student achievement tests, and distribute state and federal funding to school districts.[11]

Additionally, education in the United States is segmented between public and private schools, including religious and nonsectarian institutions.

For details on the United States' education system, see the accompanying brief "Education in China and the United States: A Comparative System Overview."

Integration of AI Education in China

Since 2017, China has released several strategic plans relevant to AI education. The most well-known of the plans—the State Council's seminal July 2017 New Generation AI Development Plan—called for implementing AI training at every level of education. Another major push in AI education is through the "Double First Class University" (双一流大学) initiative, a 2017 program under Chinese President Xi Jinping that built upon previous reforms such as Projects 211 and 985 to create world-class universities.[12] Nearly all of the MOE's directly supervised and funded 75 universities are also "Double First Class." The initiative split universities into two tracks: 42 universities were selected as world-class universities, and split respectively into 36 "Class A" (already close to being world class) and 6 "Class B" (potential to be world class) universities.[13] This initiative essentially pared down the number of top universities China was focusing on.[14] Figure 1 contains a timeline of these plans and their associated goals.

Figure 1. Timeline of China's AI Education Strategy and Implementation (2017–2020)

Date	Initiative	Launched by	Details
2017 January	"Double First Class"	MOE	Merge 211 and 985 programs to: • Boost elite universities' status to world class by 2050 (36 "class A" and 6 "class B" universities selected) • Elevate key disciplines and top talent, especially at undergraduate level (95 universities chosen to focus on key disciplines)
2017 July	"Next Generation AI Development Plan"	STATE COUNCIL	Broadly apply AI across all education levels, train a new talent generation, and construct AI discipline.
2018 January	"Next Generation AI Development Plan"	STATE COUNCIL	MOE officially includes AI, Internet of Things, and big data processing in national high school curricula; makes this coursework mandatory for high school students in fall 2018 and beyond.
2018 April	"AI Innovation Action Plan for Colleges and Universities"	MOE	By 2020, create: • 50 world-class AI textbooks • 50 national-level online AI courses • 50 AI research centers • 100 cross-disciplinary "AI + X" majors
2018 April	"Education Informatization 2.0 Action Plan"	MOE	Enrich AI and programming curricula at all levels.
2019 March	AI Major Approved	MOE	35 institutions approved to offer the AI major.
2020 January	"Accelerate Graduate Students' Training in AI Using Double First Class"	MOE, NRDC, MOF	Increase university-industry partnerships, funding, and quality control of degrees.
2020 January	"National Planning for the Construction of Teaching Materials for Universities, Primary and Secondary Schools, 2019–2022"	MOE	Textbook development on AI, big data, blockchain, cybersecurity.
2020 February	More Institutions Offer AI Major	MOE	180 more institutions approved to offer the AI major, for a total of 215.

Source: Chinese Ministry of Education, State Council.

Primary and Secondary AI Education

China is actively integrating AI education into young students' education. These efforts are primarily characterized at the primary school level with introductory Python courses, and access to labs featuring robotics, drones, and 3D printing. Local governments have recently begun awarding schools for excellence. Since 2018, the MOE has mandated high schools to teach AI coursework.

Role of Talent Training Bases

Talent training bases are one of the newer ways that AI education is gaining momentum at the primary and secondary level. Shandong Province and Beijing began awarding "National Youth AI Innovation Talent Training Base" (全国青少年人工智能创新人才培养基地) honors to their schools between November and December 2020.[15] Schools are chosen for demonstrating excellence in AI education. Primary schools are rewarded for offering rudimentary "technology and society" and "maker" courses and access to 3D printing and drones. Junior high schools gain recognition for "AI clubs," robotics rooms, 3D printers, open source AI frameworks, utilize Python, and have won robotics competitions.[16] The certification, according to images of award placards, is for two years.[17] Shandong awarded 10 schools the certification, while Beijing awarded 21, including a S&T museum for youth.[18]

Beijing appears to have had a strong start to its AI education program. As part of the talent training base initiative, one hundred teachers were awarded certificates to be "AI literacy assessors."[19] As part of the project, the Beijing Youth AI Literacy Improvement Project also laid out numerical goals for its next three to five years: it plans to support the creation of ten AI experimental areas, create one hundred AI education experimental schools, select thousands of AI education seed teachers, and train ten thousand young AI talents.[20] As the program is only a few months old, it remains to be seen what quality control mechanisms will be used, and how well Beijing will implement its goals.

Mandated High School AI Curriculum

At the high school level, the MOE in January 2018 revised its national education requirements to officially include AI, Internet of Things, and big data processing in its information technology curricula.[21] The revision requires high school students enrolled in the fall of 2018 and beyond to take AI coursework in a compulsory information technology course.[22] The coursework goals include data encoding techniques; collecting, analyzing, and visualizing data; and learning and using a programming language to design simple algorithms.[23] Python is a popular choice, and is even being integrated into the *Gaokao* as testing material in Beijing as well as Zhejiang and Shandong provinces.[24] This integration may incentivize high school students to develop Python expertise at an earlier age, and prepare them for further training at the university level and beyond. Further goals include understanding AI safety and security, and an emphasis on ethics. However, there is also a distinct emphasis on “learning to abide by relevant laws,” which could channel learning in directions considered suitable to the Party-state’s needs.

Teacher Conferences

At both the primary and secondary school level, a prominent planning and information sharing mechanism is the National Primary and Secondary School Artificial Intelligence Education Conference, which is sponsored by the nonprofit Chinese Association for Artificial Intelligence’s Primary and Secondary School Working Committee.[25] The conference focuses on teacher training, use of education platforms, and curriculum design.[26]

Role of Private Sector

Companies and schools often partner to create textbooks. In April 2018, SenseTime and the Massive Open Online Course Center of East China Normal University launched the first domestic AI textbook *Artificial Intelligence Basics (High School Edition)* for middle school students.[27] According to SenseTime, it is currently being taught in pilot programs in more than one hundred schools throughout the country in Shanghai and Beijing, as well as Guangdong, Heilongjiang, Jiangsu, Shandong, and Shanxi provinces. SenseTime is also training over nine hundred teachers to teach the material.[28] In June 2018, Soochow University Press published the "Artificial Intelligence Series for Primary and Secondary Schools." In November 2018, a Tencent-backed, globally active company named UBTech Robotics, and East China Normal University Press jointly released the "Future Intelligent Creator on AI-Series of Artificial Intelligence Excellent Courses for Primary and Secondary Schools."[29] More recently, Tsinghua University announced in January 2020 that Yao Qizhi—China's first winner of the Turing Award, academician of the Chinese Academy of Sciences, and dean of Tsinghua's Institute of Interdisciplinary Information Sciences—would be editing the textbook *Artificial Intelligence (High School Edition)*.[30]

Chinese tech giants such as Baidu are also helping to introduce AI to vocational secondary schools. For example, in July 2019, Baidu Education and Beijing Changping Vocational School launched China's first vocational school-enterprise cooperation initiative on AI education.[31] The cooperation identified five dimensions: jointly building Baidu's artificial intelligence innovation space, jointly building artificial intelligence technology and application majors, jointly building training bases for vocational college instructors, jointly carrying out teacher-student skills exchange competitions, and jointly building small and medium-sized subject general experience bases.[32]

Issues Faced

AI education at the primary and secondary school levels faces notable issues. Local education consultants note that one issue is an overly difficult curriculum for young children, especially when students require significant background knowledge to understand algorithms powered by deep learning.[33] Additional issues include a lack of systematic and authoritative guidance on textbook development, lack of professional training for teachers, and lack of equipment in underequipped school AI labs.[34]

Undergraduate AI Education

China's AI education push is most prominent at the postsecondary level. The following sections will examine the two main mechanisms for talent training: AI institutes, and the MOE's standardized AI major. The AI major is now the country's most studied field.[35]

AI Institutes

AI institutes largely preceded the MOE's development of the AI major. Both preceding and following the MOE's release of the "AI Innovation Action Plan for Colleges and Universities" in 2018, at least 34 institutions launched their own AI institutes between 2017–2018 (see Figure 2).[36] In 2018, three Seven Sons of National Defense universities joined these ranks. The Seven Sons are directly supervised by the Ministry of Industry and Information Technology (MIIT). Their core mission is to support the People's Republic of China's defense research, its industrial base, and military-civil fusion to merge civilian research into military applications.[37] Aside from three Seven Sons in 2018, at least three universities even launched their institutes before the July 2017 Next Generation AI Plan from July 2017.[38] However, it is common for institutes' "About Us" pages to cite the "AI Innovation Action Plan" and the national AI plan as its reason for creation.[39]

Unlike the AI major, which is clearly targeted as an undergraduate major, institutes are significantly more heterogeneous in their research foci, which range from natural language processing to robotics, medical imaging, smart green technology, and unmanned systems.[40] Likewise, they often train both undergraduate and graduate students, and in some cases offer the AI major within their institution.[41]

Companies also play an establishing role for AI institutes. For example, Chongqing University of Posts and Telecommunications set up an AI institute in 2018 with AI unicorn iFlytek, while Tencent Cloud established AI institutes in 2018 with Shandong University of Science and Technology and Liaoning Technical University.[42]

It is beyond the scope of this paper to examine the AI institutes' quality indicators. A forthcoming CSET data brief will examine the landscape of AI institutes, their research foci, the degree of overlap with the AI major, and their relationship to China's key laboratories in greater detail.

Standardized AI Major

In March 2019, the MOE approved 35 colleges and universities to offer the four-year AI major as an engineering degree, including four of the Seven Sons of National Defense universities.[43] Half of the institutes (17) that had previously launched AI institutes were later formally approved to launch the new AI major in the 2019–2020 range. The approval of a new AI major was a notable change from past curricula, when AI was available as a concentration within the computer science major at some universities.

In February 2020, the MOE approved 180 more universities—a fivefold increase—to offer the AI major, bringing the total number of approved universities to 215. One of the approved was a fifth member of the Seven Sons.[44]

In March 2021, the MOE approved 130 universities, including the sixth and seventh of the Seven Sons, bringing the total university count to 345.[45] In both 2020 and 2021, the AI major was the most popular new addition to universities' curricula; in 2021, the next most popular majors included 84 universities offering intelligent manufacturing and engineering, and 62 offering data science and big data technology.[46] Additionally, eight universities that had launched AI institutes between 2016–2018 have also begun offering the AI major. The vast majority of these universities are not well known or are business oriented, with the clear exception of Tsinghua.

Tsinghua University's AI Offerings

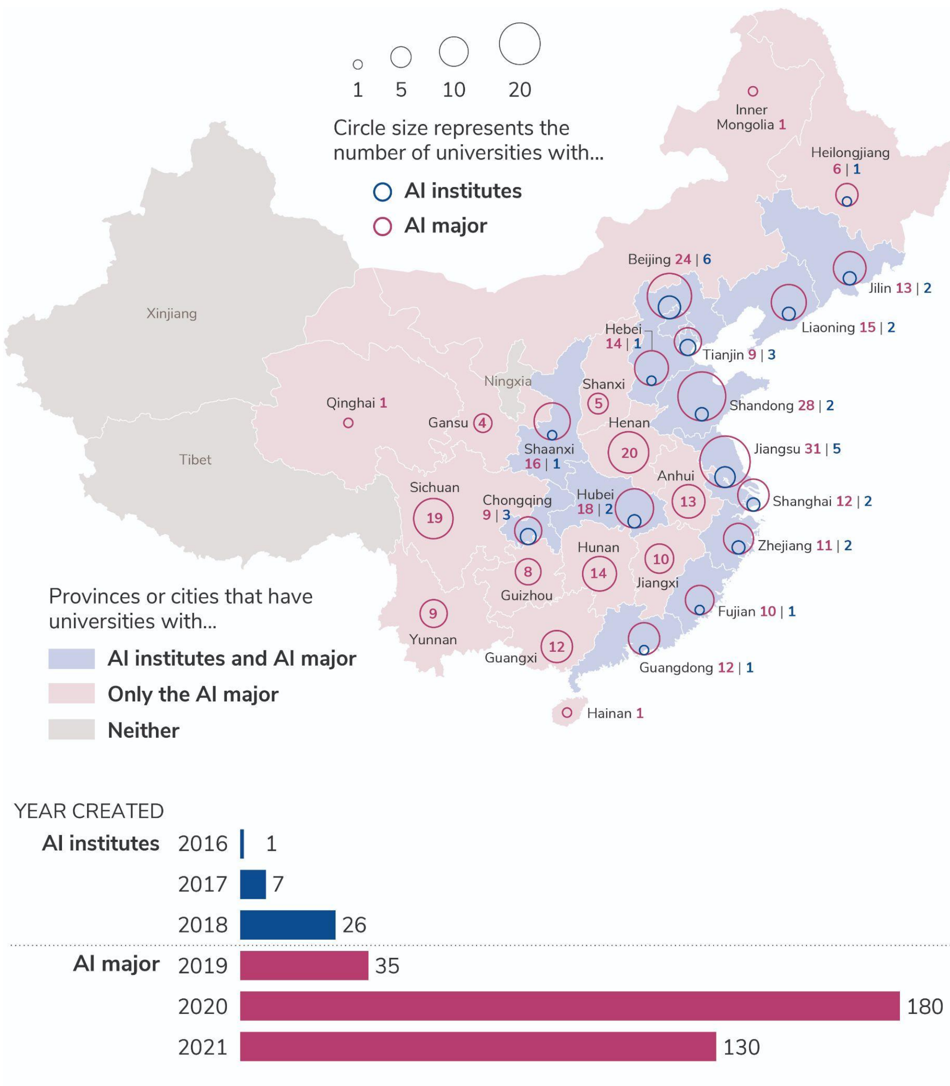
Tsinghua had an early foray into AI teaching. In 1979, the predecessor to today's Department of Electronic Engineering opened the "Introduction to Artificial Intelligence" course, which was one of the earliest AI courses offered by any Chinese university.[47] In the late 1980s, the Department of Computer Science and Artificial Intelligence of Tsinghua University established the State Key Laboratory of "Intelligent Technology and Systems," also known as the "Institute of Human Intelligence."[48]

While Tsinghua was only approved in March 2021 to offer the AI major, it already offered AI education via various channels and opened its interdisciplinary Institute of Artificial Intelligence in June 2018. In May 2020, Tsinghua announced the creation of an AI "smart class" (智班), which will be the 8th experimental class of the "Tsinghua Academy Talent Training Program." Yao Qizhi, who also spearheaded the aforementioned high school AI textbook, will serve as the lead faculty in an interdisciplinary "AI + X" approach, which entails integrating AI with mathematics, computer science, physics, biology, psychology, sociology, law, and other fields.[49]

In 2019, Tsinghua also combined three minors—Robot Technology Innovation and Entrepreneurship (机器人技术创新创业), Intelligent Hardware Technology Innovation and Entrepreneurship (智能硬件技术创新创业), and Intelligent Transportation Technology Innovation and Entrepreneurship (智能交通技术创新创业)—into one new major titled Artificial Intelligence Innovation (人工智能创新).[50]

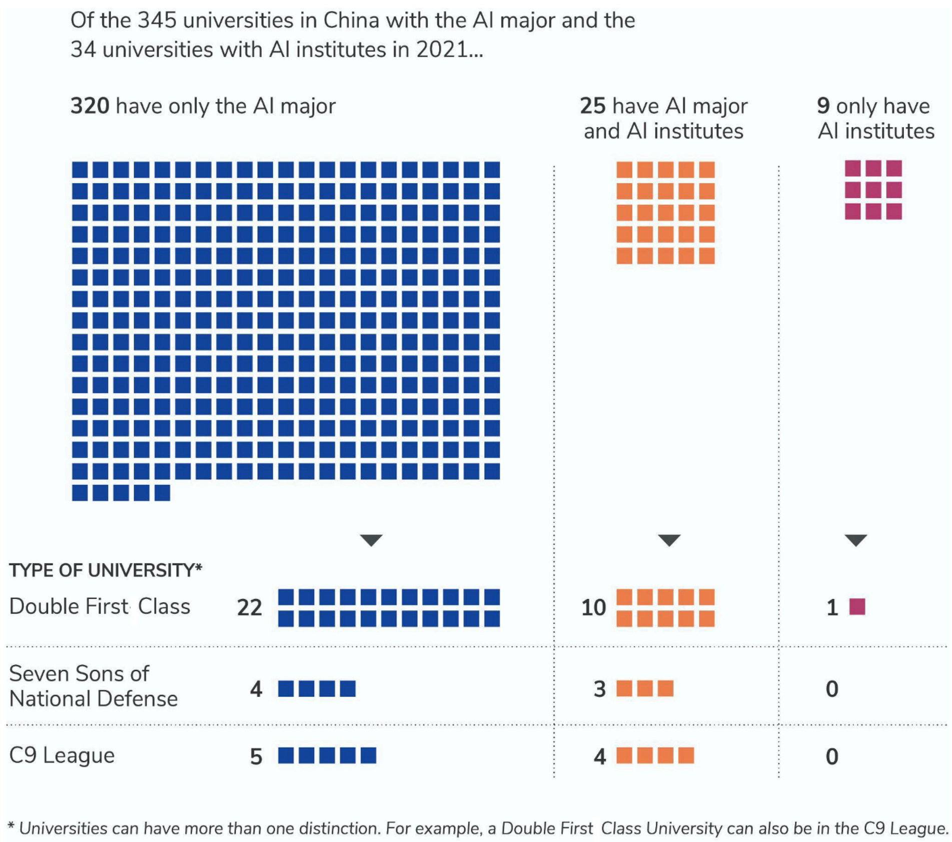
Figures 2 and 3 breakdown China's 345 universities with AI majors and 34 AI institutes, as well as the number that are "Double First Class," Seven Sons, and the Ivy League-equivalent C9 League.[51] Figure 2 presents the information geographically while Figure 3 provides a breakdown by type of institution.

Figure 2. Map of Universities Offering the AI Major and AI Institutes



Source: Ministry of Education, Synced Review, CSET calculations.

Figure 3. Share of Elite Universities Offering AI Major and AI Institutes



Source: Ministry of Education, Synced Review, CSET calculations.

A Chinese AI company called KXCY AI working with several elite Chinese universities suggests that the AI major's goals are to meet national economic and technological development needs, develop knowledge of basic AI theories, learn research and development (R&D) skills, along with system design, management, and solving complex engineering problems in AI and related applications.[52] Further, colleges and universities with existing AI programs were encouraged by the MOE in 2018 to expand their scope to establish "AI + X" majors.[53]

Beyond the AI major, AI-adjacent majors include data science (数据科学), a major in its fifth year of operation, while other majors include big data technology (大数据技术), intelligent manufacturing (智能制造), robotics engineering (机器人工程), and intelligent science and technology (智能科学与技术).[54]

Role of Private Sector

China's AI enterprises play a significant role in developing AI talent and providing resources to universities through formalized partnerships. One such mechanism is the Information Technology New Engineering Industry-University-Research Alliance (信息技术新工科产学研联盟, or AEEE), founded in 2017 to bolster technological innovation within the industry-university-research nexus. Its founding members included the China Software Industry Association, 27 domestic universities, five research institutes, and 12 companies, with support from MOE's Higher Education Department and MIIT.[55] Chinese companies include Baidu, Alibaba Cloud, Tencent, Huawei, and China Telecom. Of the 27 Chinese universities, 21 offer either an AI major, institute, or both. The roster further includes all Seven Sons of National Defense, and the entire C9 League.[56] The AEEE universities include China's most elite institutions.

Of note is that the AEEE also includes U.S. companies Cisco, IBM, and Microsoft.[57] A blog post from Microsoft Research Asia (MSRA) from April 2019 indicates its founding role in the alliance's AI Education Working Committee, its work towards implementing the MOE's "industry-education integration" (产教融合理念), as well as the award it subsequently received from the alliance for its contributions in curriculum construction, resource sharing, and teacher training.[58] MSRA further states it has partnerships with University of Science and Technology of China, Xi'an Jiaotong University, Harbin Institute of Technology (a Seven Sons university with its own AI institute and major), Nanjing University and Zhejiang University, while its AI education seminars have helped three hundred colleges and universities across the country and more than five hundred AI teachers.[59] In March 2019, MSRA also worked with another Seven Sons institute, Beihang University, to open a course called "Real Combat in Artificial Intelligence," which attracted at least 30 Beihang students from across 10 majors that year.[60]

Baidu also plays a prominent role in both the alliance and beyond. It is one of China's three internet giants, and an "AI champion" as appointed by the Ministry of Science and Technology, working on autonomous driving.[61] Between 2018 and 2021, Baidu has signed at least nine AI partnerships with universities. These partnerships are designed for sharing case studies or challenging issues faced in the field, jointly constructing courses, teacher training, campus learning communities, launching competitions, and internship training.[62]

These partnerships also provide AI Studio training. AI Studio is an AI educational service offered by Baidu, based upon its deep learning platform PaddlePaddle. It provides an online programming environment, free GPU computing power, massive open source algorithms and open data to help developers quickly create and deploy models. AI Studio has 15 partner universities—all but four either offer the AI major, an AI institute, or both.[63]

Graduate AI Education

As alluded to in Figure 1, China signaled it understood the importance of graduate students advancing AI development when the MOE, National Development and Reform Commission, and the Ministry of Finance released a plan in January 2020 calling for increased training for AI graduate students. The plan's key goals are centered on using the aforementioned "Double First Class" program and interdisciplinary "AI + X" framework to bolster talent development and increase the number of grad students studying AI, especially at the doctoral level.[64] Talents are called upon to apply AI to industrial innovation, social governance, national security, and other fields, and support the mission and needs of major national projects and major development plans.[65]

Additionally, the plan stated AI will be incorporated into the "Special Enrollment Plan for the Cultivation of High-level Talents in

Key Fields Urgently Needed by the State" ("国家关键领域急需高层次人才培养专项招生计划"). This incorporation has already led to increased supply of AI doctoral positions at institutes such as Nankai University.[66]

The plan also emphasizes quality control. The degree evaluation committee has established an artificial intelligence working group (高校学位评定委员会设立人工智能专门工作组) responsible for developing advanced AI talent training programs, degree standards and management norms, and performing random quality control inspections of AI dissertations.

As with all levels of AI education, China's AI companies are asked to partner with universities—partnerships focus both on training teachers and students. At the postgraduate level, there is meant to be a revolving door between industry and universities. First, at the instructor level, companies are encouraged to train university instructors in the latest cutting-edge methods. Instructors are asked to incorporate the latest research findings in AI into doctoral courses. From the company side, leading researchers at these companies can also do research through "double employment" at universities.

Second, companies are asked to train graduate students by having them solve industry needs. For doctoral students, enterprises are also encouraged to open up "scenario-driven," application-oriented courses, as well as their data, case studies, tools, and training platforms. Enterprises can also utilize industry alliances, joint R&D labs, entrepreneurship and skills competitions, and certification training to help graduate students grow in the field.

There is also an emphasis on increased and coordinated funding at the university and enterprise levels. Universities are encouraged to coordinate various resources, such as financial investment and scientific research income, increase support for graduate training, carry out basic frontier research and key common technology research efforts. With enterprises, methods such as angel investment, venture capital, and capital market financing can boost major AI projects and applied research within universities, as well as assist with talent training.

Although it remains too early to tell how well these policies will tangibly advance China's talent training and AI capabilities, China's efforts over the last 20 years in prioritizing and progressing in key areas such as hypersonics and biotechnology indicate that policies are not just wish lists, but backed up by measurable results. Nonetheless, we caution that widespread, haphazard curricula construction for the sake of participating in the "AI gold rush" could hinder these successes. If China is able to fulfill the tall order of ensuring rigorous quality control from its wealthy metropolises to its under-resourced regions, we assess that China could replicate its past successes in policy implementation.

Integration of AI Education in the United States

Integration of AI curricula in the United States is uneven in both depth and scope as it remains the work of states and local school districts to finalize and implement curriculum standards. In recent years, various organizations and companies have helped facilitate progress through efforts to define and establish AI curricula, programs, learning standards, and resources for teachers and students who want to add AI to their education.

Primary and Secondary AI Education

AI and Computer Science Curriculum

Numerous states have recently taken steps toward integrating AI into K-12 classrooms. This often starts with computer science curricula, when available at the school, as it is viewed as a first step towards an AI specialization. However, many schools still lack CS education. From 2019 to 2020, 28 states adopted policies to support K-12 CS education, with efforts disparate across and within states. According to a 2020 report from Code.org, the portion of public high schools teaching CS are as high as 89 percent in Arkansas and as low as 19 percent in Minnesota.[67] Moreover, only 22 states have adopted policies that provide *all* high school students access to CS courses, and of those states, only nine give all K-12 students access.[68] Only 47 percent of U.S. public high schools teach CS,[69] although that is up from 35 percent in 2018.[70]

Within the movement among states to adopt CS curricula, the content and learning standards of such curricula will vary by state as each maintains authority over curriculum standards. Different organizations have formed unique versions of CS education standards that present schools with options or frameworks for teaching AI in the classroom. The professional association Computer Science Teachers Association in 2017 released a “core set of standards” to guide teachers in computer science.[71] The International Society for Technology in Education, a nonprofit headquartered in Washington, DC, collaborated with the CSTA to release its ISTE Standards for Computer Science Educators in 2018.[72] CSTA also played a role in developing another set of K-12 CS guidelines, along with the Association for Computing Machinery, Code.org, the Cyber Innovation Center, CS4ALL, and the National Math and Science Initiative, to develop the K-12 Computer Science Framework. Nonprofit Code.org offers K-12 students and educators CS curricula embedded within STEM courses already offered.[73] The initiative serves as a conceptual guide to inform curriculum development, and it prioritizes computing systems, cybersecurity, data science, algorithmic programming, and social and cultural impacts of computing.[74]

Not all STEM and CS education initiatives explicitly state the connection to AI education, but some initiatives do. AI4K12 is an initiative born from a partnership between the Association for the Advancement of AI and CSTA and was funded by the National Science Foundation (NSF) and Carnegie Mellon University.[75] AI4K12's goal is to develop national AI education guidelines for K-12. It currently serves as an online repository of resources for educators. The nonprofit AI Education Project is another example of an organization offering its own AI curriculum to schools and educators nationwide.

At least two public schools have developed their own AI curricula. Seckinger High School in Gwinnett County, Georgia, will be the first to introduce a curriculum for AI education to an entire K-12 cohort.[76] The North Carolina School of Science and Mathematics, a high school administered by the University of North Carolina system, announced The Ryden Program for Innovation and Leadership in AI to teach high schoolers how to design, use, and understand AI.[77] Thus far, the content of these AI curricula can vary. Seckinger High School's AI curriculum, for example, teaches coding, machine learning, design thinking, data science, and ethics and philosophical reasoning at each level of its K-12 education.[78] The Ryden Program emphasizes that students understand "how to merge humanity with machine learning," and how AI can solve complex problems affecting society.[79]

Teacher Training

For public school educators, each state governs the formal licensing and accreditation process. This process can vary widely by state, and even year to year, as states implement reforms or update testing, certification, or license requirements.[80] Moreover, private or religious schools usually have more autonomy in setting requirements for educators, which introduces another degree of variation for how AI curricula might be taught.[81] These variations could result in uneven standards for educators and therefore affect quality.

Ultimately, multiple components factor into preparing educators to teach AI and CS, such as community support groups, training and professional development, or microcredentials or certificates. Therefore, an additional hurdle to competitive teacher training is adequate access to the resources required to teach AI effectively.[82] Some states have already spent years integrating CS curriculum in schools and training its educators accordingly.[83]

Role of Private Sector

The private sector is supporting CS and AI integration into primary and secondary education through a number of different initiatives with distinct goals. CSET analysis found over three dozen such programs; all are a mix of private companies, nonprofits, and public-private partnerships that offer AI curricula, learning materials, and conferences for students and educators in the United States.[84] For example, Microsoft Philanthropies operates the Technology Education and Literacy in Schools (TEALS) program in roughly 455 high schools with the goal to “build sustainable CS programs” for underserved students and schools, especially rural ones.[85] Amazon Future Engineer, a sub organization of Amazon, supports CS curriculum access to teachers in underserved public school districts and claims to reach more than 550,000 K-12 students.[86]

In addition to working AI education into the classroom, the private sector is expanding opportunities to learn about AI outside of the classroom. An estimated three hundred different organizations now offer AI or CS summer camps to K-12 students. Private companies organize a number of these and host them at competitive universities such as Stanford, the Massachusetts Institute of Technology, and Carnegie Mellon. Companies and organizations have also expanded AI learning opportunities to K-12 students by offering after school programs, competitions, and scholarships. Some initiatives explicitly focus on reaching U.S. students that otherwise may not have access to AI education through formal schooling. Girls Who Code, TECHNOLOchicas, and Black Girls CODE are just three of many organizations that specifically service underrepresented groups in CS education to address gender and race disparities in CS education.[87]

Issues Faced

Differences in the design and deployment of AI education across states make it difficult for U.S. schools to consistently define "AI education," justify investment in AI education with limited resources, and provide adequate training to educators. Whereas some AI education initiatives prioritize CS, programming languages, math, and data science, others emphasize non-technical areas such as societal and ethical impacts of AI applications.[88] For example, private company ReadyAI's programs emphasize the nontechnical components of AI, such as art and multimedia, whereas Microsoft TEALS' curriculum focuses on technical skills such as Java and Python programming languages. Investment in AI education also becomes a challenge since such a piecemeal approach makes it difficult for educators and education leaders to assess which learning programs are effective.

Whichever approach states pursue, the result is a disjointed implementation of AI education. Accordingly, private and nonprofit sector organizations are taking on efforts to coordinate across state lines in conjunction with state governments and professional teachers' associations. Still, most of these efforts function as guides, resources, and suggested standards.

Postsecondary AI Education

For most U.S. colleges and universities, the closest thing to an AI major remains CS degrees with AI concentrations or specializations. Nevertheless, these postsecondary CS/AI course offerings are growing rapidly. According to the 2021 AI Index Report, the number of AI-related undergraduate courses increased by 102.9 percent and 41.7 percent at the graduate level in the last four years.[89] Growth rates in undergraduate and master's CS degrees were similarly high. Doctorate awards in CS have also increased, by 11 percent since 2015, as have those with a specialization in AI.[90]

In addition to the increase in AI course offerings, many federal agencies are also prioritizing investment in AI higher education. For example, the 2021 National Defense Authorization Act directs the NSF to fund AI initiatives for higher education, such as fellowships for faculty recruitment in AI, as well as AI curricula, certifications, and other adult learning and retraining programs.[91]

Undergraduate AI Education

At the undergraduate level, integration of AI education varies and often depends on the type of institution or the availability of industry collaboration. In community colleges and technical schools, there are few AI-specific education initiatives with the exception of several recent industry partnerships with companies such as Amazon, Google, and IBM.[92] Moreover, some states have better resourced community college CS programs that may be better equipped to integrate AI curricula. For example, over 10 percent of CS associate degree graduates come from Northern Virginia Community College, one of the community colleges partnering with Amazon to offer a cloud computing curriculum.[93]

Data from the 2021 AI Index Report show that many universities have augmented bachelor's degrees in CS with a specialization in

AI or machine learning.[94] For example, Stanford University and the California Institute of Technology both offer bachelor's of science degrees in CS with an AI specialization track. The University of Illinois confers a bachelor's of science in computer engineering with a specialization in AI, robotics, and cybernetics. The University of Minnesota's AI specialization track includes classes in AI, machine learning, data mining, robotic systems, and computer vision. The University of California San Diego offers a computer science degree with an area of interest in AI through its Jacobs School of Engineering.

Moreover, some universities are making AI educational content available to everyone. CalTech and Stanford, for example, are opting to provide AI-related coursework online to both students and the general public. Harvard University and MIT, through their online learning platform edX, also provide both free and low-cost options for AI education.

Graduate AI Education

In contrast to undergraduate programs, more postgraduate institutions offer AI majors and degrees instead of AI specializations within a CS degree, particularly at the master's level. For example, Colorado State University, UC San Diego, and Johns Hopkins are just a few universities now offering master's of science degrees in AI. At the doctorate level, some programs offer a PhD in AI or ML, while many others mirror the undergraduate approach to offering a degree in CS with an AI specialization.

Also at the graduate level, a number of globally competitive U.S. universities are leading in AI education and research. Such programs are known for industry and government collaboration: Carnegie Mellon University's AI and CS programs collaborate with both the private sector and government in AI-related fields such as autonomy, robotics, and 3D printing. Amazon AWS is a sponsor of CalTech's AI4Science Graduate and Postdoctoral Fellows program, a cross-disciplinary approach to AI research. MIT's Computer Science and Artificial Intelligence Laboratory is recognized as a hub for AI innovation and is home to nearly three dozen research groups, research centers, and communities of research in AI and machine learning.[95] As previous CSET research has shown, at the graduate level, the United States is able to attract and train top-tier AI talent.[96]

Role of Private Sector

The private sector is assisting in the development of course design for postsecondary AI education, from certificate and online learning programs to two- and four-year degrees. For example, IBM is collaborating with online learning platform Simplilearn for its certificate in AI. AWS offers machine learning courses on learning platform edX, and Google has a similar partnership with Udacity and offers deep learning courses on its online education platform. Partnerships also exist between industry and degree-granting institutions. For example, Amazon is partnering with the Virginia Community College System and six Virginia universities to teach students cloud computing. In Arizona, the Maricopa County Community College District is working with Intel on Arizona's first AI certificate and degree program. IBM's P-TECH program prepares high schoolers and community college students for careers in tech, also offering free online courses in AI and cloud computing.

In 2020, the NSF announced its funding of a joint industry-government AI initiative that includes the U.S. Department of Agriculture, the National Institute of Food and Agriculture, the U.S. Department of Homeland Security Science and Technology Directorate, and the U.S. Department of Transportation Federal Highway Administration. The initiative established 18 new AI Research Institutes, which each have a component related to AI education.[97] Industry cosponsors, Accenture, Amazon, Google, and Intel, put $160 million toward the institutes, which will support a range of interdisciplinary AI research ranging from cyber infrastructure, biology, ethics, and agriculture.[98]

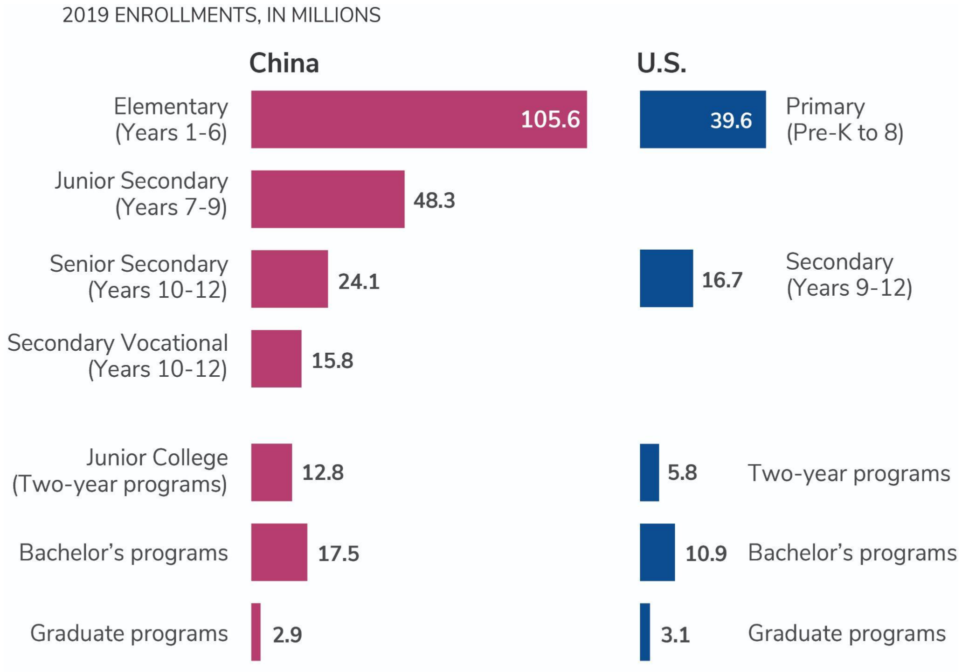
Implications for U.S. AI Workforce Competitiveness

The relative efforts of the United States and China to build a globally competitive domestic AI workforce have potentially major and long-term national security implications. Policymakers at all levels of the U.S. government would be wise to consider these implications when designing future S&T education and workforce policies. We discuss strengths and shortcomings for each country followed by an assessment of implications.

China's Strengths and Shortcomings

Over the last decade, China made significant progress in its short-, medium-, and long-term strategic plans for cultivating an S&T workforce. It has fairly effectively embedded AI education and training into each phase of the workforce development pipeline. China's progress in incorporating AI education at all levels is notable given the large size of its student population relative to the United States. Figure 4 shows 2019 enrollment totals by level of education for China and the United States (2019 graduate totals by level of education are provided in the Appendix). China maintains a cumulative numerical advantage until the graduate level, after which the United States retains a slight lead. This lead disappears when not counting foreign-born students, who comprise about 14 percent of total graduate enrollment. However, as a share of total population in each country, the United States remains far ahead.

Figure 4. 2019 Total Educational Enrollment, United States and China



Notes: Some U.S. school districts split primary school into "elementary school" and "middle school" or "junior high school." Middle school and junior high school typically consists of grades 6-8 or 7-8. Chinese postsecondary figures do not include adult or web-based institutions

Source: 2020 Digest of Education Statistics, U.S. National Center for Education Statistics; 2020 Chinese Statistical Yearbook.

Although the United States leads in graduate enrollment, when looking at graduate breakouts in STEM, the lead reverses. In fact, China's lead in advanced STEM education has only increased over the last five years. As shown in Figure 5, China is graduating more doctorate degrees in science and engineering than the United States in STEM. It is clear that advanced degrees in China emphasize these disciplines — 59 percent of doctorates and 41 percent of masters awarded in China in 2019 were in these two fields, compared to about 16 percent of U.S. graduate degrees being in STEM.[99]

Figure 5. China Has More STEM Postsecondary Degrees Than the United States

Source: 2020 Digest of Education Statistics, U.S. National Center for Education Statistics; China's Ministry of Education.[100]

Still, China's progress is not without challenges. One of its largest hurdles to having a more uniformly educated AI workforce from all parts of the country is the household registration system, or 户口 (*hukou*), which controls intra-regional labor distributions by assigning legal residents permits based on the head of household's birthplace.[101] Despite ongoing reforms, the *hukou* system still provides stratified availability of social benefits based on individuals' registration, rather than where they live.[102] This makes it very difficult for youths with rural *hukou* to obtain education beyond the compulsory level.[103]

Inequities stemming from the urban-rural divide also bleed into China's AI education pipeline. For example, while well-resourced primary and secondary schools in Beijing can afford to build 3D printing and robotics labs, poorer parts of the country may not have such advantages from an early age, or have adequately trained teachers.

Educational access and quality in China largely depend on location and socioeconomic status—urban residents are far more likely to have positive intergenerational mobility versus those from rural areas. Despite national reforms, rural populations experienced "nonexistent" effects.[104] The main drivers were poor policy enforcement and insufficient educational reforms.[105] MOE data from 2020 also indicates additional challenges. Rural primary schools are closing and enrollment is declining.[106] An underlying reason behind these numbers is the continual migration patterns of rural *hukou* holders into urban areas, leading to closure of village schools.

Further, the MOE may have mandated AI education in high schools from fall 2018 onwards, but it is no trivial task to implement education of uniform quality or properly enforce quality control. If students in less well-resourced areas only have the means to memorize patriotic AI propaganda and do not receive the same caliber of AI education, it could exacerbate a deepening digital divide and economic inequality.[107] It also remains to be seen whether China's AI education will spur creative thinking and teamwork, or plug students into carrying out repetitive tasks to design things such as "simple algorithms."[108]

China also faces issues in teacher quality. There is a higher student to teacher ratio in poorer areas, and loss of teacher talent to more developed areas is common. Since poorer parts of the country lack funds to hire and properly train teachers, there are fewer, less-qualified teachers per student.[109] However, the Chinese government has implemented policies such as recruiting graduates from universities to work for three years in rural schools in central or western China, and required teachers in large and medium cities to regularly work for short periods in rural schools.[110] Rural teachers can also apply for continued learning and training at teacher training institutions.[111]

U.S. Strengths and Shortcomings

U.S. efforts to embed AI education into its training pipeline have been mixed. A few noteworthy K-12 AI education efforts stand out, such as Gwinnett County's first U.S. public AI high school and an increasing number of schools implementing CS curricula. Moreover, data shows that the NSF-funded 2016 Advanced Placement CS Principles (AP CSP) course brought in more diverse groups of students studying CS in high school and postsecondary education.[112] Yet, across the U.S. K-12 education system as a whole, integration of AI education is lopsided as inequities in quality and access persist.

At the postsecondary level, the United States shows more progress. NSF's multi-agency program solicitation for 18 new AI institutes reflects strengthened collaboration between the government and private industry.[113] Additionally, large public universities and private universities generally have more resources and greater motivations to remain competitive in providing high-quality education. A number of institutions have either supplemented CS education with specializations in AI or added AI degrees and majors. Still, while this is encouraging, we note this does not make up for what is lost in early K-12 exposure or for youth who do not attend college. For youth that do attend college, research shows many have already decided against pursuing STEM fields before they even arrive.[114]

An additional challenge for AI education in the United States is the ability to recruit teachers with CS or AI expertise since industry is usually a more attractive option.[115] This creates quality gaps when it comes to teaching CS or AI curricula in U.S. classrooms. Moreover, in certain school districts, paid teacher training is not offered for CS or AI, and even when accessible, CSTA has described the CS certification process as "confused, disparate and sometimes absurd."[116] Additionally, in lower-income and rural school districts, educators may already be teaching multiple subjects.[117] Therefore, tasking those educators with an additional CS or AI course may not be feasible.

Implications

China has benefited from its centralized, systematic approach to implementing AI education at all levels. Provincial education bureaus reward primary and secondary schools for offering curricula on AI basics, the MOE mandated AI curriculum at the high school level, and the MOE approved 345 universities to offer the standardized AI major, China's most popular new major today. At least 34 universities also have AI institutes, which provide undergraduate and graduate training and research. At the postgraduate level, the MOE called for increased support for AI students through company and venture capital funding, and for companies and universities to partner on training and solving industry needs. Coupled with a growing numerical advantage over the United States in STEM graduate degrees, China is well-equipped to develop a robust, medium-term AI workforce pipeline. However, one major hurdle to a longer-term pipeline to closely observe going forward is China's rapidly aging population, which is not being replenished by sufficient births despite the abolished one-child policy.[118] In July, China even moved to end all restrictions and fines for surpassing the three-child quota, effectively allowing limitless births.[119]

China's progress may also help its military-civil fusion (MCF) efforts, which could undermine U.S. national security if these efforts increase Chinese military competitiveness. As indicated in Figure 3 above, half of the 42 Double First Class universities offer the AI major, and 10 offer both the major and have their own AI institute. The DFC plan is designed to mesh these universities into the MCF R&D pipeline, and therefore originate innovations—including in AI—that help both the military and civilian sectors.[120] Further, all of the Seven Sons universities offer the AI major, and about half have institutes. Previous CSET research has found three-fourths of graduates recruited by Chinese defense SOEs are from the Seven Sons, raising concerns that those equipped with AI skills and capabilities are directly entering the defense workforce.[121]

The United States benefits from greater freedom and flexibility in its education and training system. At its best, U.S. states and local governments have the freedom to innovate in education. Flexibility creates opportunities for integrating innovative curricula designs, new approaches in pedagogy, and experimentation in how students interact with and learn about AI. Similarly, braided funding models draw from a number of stakeholders, enabling schools to offer a greater variety of learning opportunities and experiences inside and outside of the classroom. This diversity contributes to the engine of innovation that has long been a hallmark of American society.

However, our analysis suggests these strengths are also a weakness when it comes to quickly leveling up the U.S. workforce for AI and other emerging technologies. At its worst, differences in school districts' funding create educational disparities, while funding structures limit the ability for long-term planning. Not all states can take advantage of the flexibility inherent in current governance and funding structures. Some states have more resources than others, better access to quality teachers, and different prioritization of AI and CS education. Flexibility can be a strategic advantage only if school districts use it, especially with a focus on quality and equity in opportunity. As an additional challenge, braided or fractured funding initiatives are difficult to track, evaluate, and scale, limiting the reach of any programs that are particularly successful or innovative.

These realities are exacerbated by a U.S. education and training system that relies on piecemeal or localized initiatives, especially when it comes to private sector involvement. For example, in contrast to China's MOE directives that directly enlist the private sector in AI education, including in defense-relevant applications, the United States is far less systematic and has many one-off arrangements. While some are an advantage when they target and serve demographic groups that may be overlooked by public education, too many AI education initiatives could become a potential downside when it results in disunity for AI education standards.

However, one of the issues the United States can claim as an enduring advantage is greater ethical and academic freedom. China's high school curriculum reforms from January 2018 emphasized following relevant laws and ethical concepts. Despite China's increasing emphasis on ethics, such as through the 2019 Beijing AI Principles, the previously mentioned SenseTime high school AI textbook does not include ethical quagmires such as the Trolley Problem, fake news, data privacy, or censorship.[122] It is also possible that given these companies are involved in controversial fields of AI such as surveillance, they may also bias how students view AI.[123] If students receive a limited view of how AI can be used in service of the state's security interests and are discouraged from criticizing these uses as unethical, that carries implications for academic freedom and China's status as a world leader in AI.[124] Critics of the Chinese education system have argued that even with generous funding, greater academic freedoms and university autonomy will be needed to establish true world-class universities.[125]

The United States is actively encouraging private industry, non-profits, and academia to prioritize AI safety and ethics. For example, the NSF AI Research Institutes are designed to ensure AI is developed transparently, reliably, and in line with American values.[126] Moreover, in 2021, the White House issued guidance to federal agencies on principles and policies to ensure AI protects privacy and civil rights.[127]

Ultimately, China's approach to AI education is incompatible with the values, design, and structure of the U.S. education system. The U.S. would instead be best served to leverage the strengths—and mitigate the weakness—of its education system to produce the AI workforce of the future. As this report shows, a key factor in U.S. AI workforce competitiveness will be how it addresses these challenges to grow and sustain the AI talent pipeline going forward.

It is not a foregone conclusion that the United States cannot compete in cultivating a leading AI workforce and we advise caution with that interpretation. For example, some critics of the U.S. education system lament that the United States is only at an inherent disadvantage. In this view, China will out-educate and train AI talent relative to the United States given its ability to mandate curricula and education offerings, and given its ability to fund and execute national education strategic plans. Meanwhile, the United States is stuck, unable to agree on core curriculum, equitably fund access to quality education, and perform well on international mathematics assessments let alone compete in AI education.

Several key advantages for the United States should factor into any discussion of system trade-offs. The potential value of the pockets of innovation in AI education throughout the U.S. education system are large, especially when appropriately targeted. This would not be possible in a more centralized system. At the graduate level, which educates a critical segment of the AI workforce, the United States remains in first place. The United States also remains the destination of choice for top-tier foreign-born AI talent working towards a doctorate. Previous CSET research showed that despite China's two decades of talent recruitment drives, nationals either do not return or do so part-time, mostly due to workplace politics.[128] Meanwhile, 91 percent of top Chinese students with U.S. AI doctorates are still in the United States five years after graduating.[129]

Conclusion

Both the United States and China have made significant progress in adopting AI education over the last five years. Their efforts show ambition in growing and cultivating a globally competitive AI workforce; however, they also reveal the structural challenges resulting from each country's education systems that potentially hinder widespread implementation of quality AI education.

This brief sheds new light on these efforts by offering a comparative assessment. We discuss the structural characteristics of the two education systems and the resulting barriers or strategic advantages the two systems lend to the adoption of AI education.

China's efforts to increase AI education at all levels bears important implications. Standardized curricula, centralized plans for implementing AI education, and explicitly calling upon companies to help universities all grant China higher likelihood of developing a robust talent pipeline for solving AI challenges. In addition, Western companies such as Microsoft Research Asia have worked with some Seven Sons and other Chinese universities through formalized partnerships involving curricula development.

The United States is working to integrate AI education into its classrooms, but the decentralized nature of its education system means it has a more piecemeal approach. Moreover, the United States is still heavily focused on tackling CS education over AI. In the same year that China laid out its AI education goals in its New Generation AI Development Plan, the United States' main CS teacher's association released new curriculum standards for CS at the primary and secondary education levels.[130] Recent years have seen a flurry of initiatives, programs, and private companies emerge in the AI education space, but there is neither a cogent vision nor a cohesive national standard guiding the focus of such efforts.

However, this does not mean AI education and training in the United States is inherently at a disadvantage. A greater degree of educational autonomy in the United States gives breathing room for experimentation, creativity, and innovation among U.S. companies and educational institutions. The challenge is for these experiments and initiatives to be evaluated and scaled successfully and inclusively throughout the entire education system.

To leverage this advantage, U.S. states will need to engage in targeted and coordinated efforts with unprecedented levels of support for long-term AI educational and workforce policies. Currently, each presidential administration and congressional legislative session ushers in new funding priorities coupled with new visions of federal roles and responsibilities. Similarly, each state has a different vision for K-12 education and associated curriculum, along with different resources and ability to make major changes. U.S. AI education efforts will be the most effective with consistency over time, unaffected by the election cycle, with assured state and local access to the requisite resources for schools, educators, and students.

Ultimately, if there is no consensus between states or at the federal level on the best way forward in AI curriculum, it is unclear who is determining what "successful" or "comprehensive" AI education looks like. A similar problem already afflicts CS education,[131] and resulting achievement gaps from inconsistent curriculum could hinder U.S. AI workforce competitiveness. The U.S. education system risks continuing along the same path for AI education, that misses certain demographics and low-income or rural schools.[132]

Our assessment suggests that to effectively face the competition presented by China for AI leadership, the United States needs to address some of the challenges inherent with its decentralized system and approach. We also suggest future U.S. S&T education and workforce policy should be considered in a globally competitive context, instead of viewing it myopically as a domestic challenge. That consideration includes recognizing and capitalizing upon the United States' enduring advantage in attracting elite talent, including Chinese nationals. While this brief does not make policy recommendations for the U.S. education system, the forthcoming CSET report, “U.S. AI Workforce: Policy Recommendations,” will.

It is no small task to take a national vision for AI education and implement it effectively in thousands of school districts across the country. This will require collaboration and coordination across federal, state, and local levels and appropriate resourcing. If not made a priority, AI education shortcomings could have long lasting consequences for the global competitiveness of the U.S. AI workforce.

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