Translation

The following white paper co-authored by China's prestigious Zhejiang University and Chinese tech company Baidu examines China's system for AI training in depth. Pointing to the United States' dominance in AI talent, the authors urge closer and more rational cooperation between Chinese universities and tech companies in training AI talent to improve China's self-sufficiency in AI. The authors also call for China to establish an international standards body for AI talent training.

Title
China Artificial Intelligence Talent Training Report
中国人工智能人才培养报告

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Source
CZ-ROBOT (创泽智能机器人集团股份有限公司) website. CZ-ROBOT is a Chinese manufacturer of service robots. The report is dated January 2022.

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China Artificial Intelligence Talent Training Report

Institute of China's Science, Technology and Education Policy,
Zhejiang University

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Contents

I. Iterative Trends and Features of the Global AI Industry

With the rapid development of science and technology (S&T), the theory and technology of artificial intelligence (AI) is becoming more and more mature, and AI's scope of application is constantly expanding, with aspects such as intelligent search, combinatorial scheduling (组合调度), intelligent perception, pattern recognition, logic programming, complex systems, and humanlike thinking (人类思维) having received extensive attention and research. During efforts to prevent and control the spread of the COVID-19 epidemic, the value of AI applications was demonstrated to an enormous degree, as large numbers of tools based on intelligent algorithms and technology were successfully introduced and applied. From a global perspective, many countries have elevated AI to the national security level, and there is a growing consensus around laying out and seizing the "high ground" (高地) in AI. AI plays a very important role in a country's sustainable economic development, industrial upgrading and transformation, and S&T progress, and its goals coincide with the key direction of China's future development.

A. Waves of Development in the Global AI Industry

In 1956, the Dartmouth Workshop proposed the concept of "artificial intelligence" for the first time, opening the curtain on the development of the AI industry. In the course of over sixty years of development, AI has experienced three waves of development, and it is currently in the third wave. First wave: When the concept of "artificial intelligence" was introduced in 1956, it set off the first wave of AI development, the core of which was to give machines the ability to reason logically and to develop the first perceptron software and chat software. Second wave: The second wave of AI got underway in the mid-1970s. Hopfield neural networks and behavior tree (BT) training algorithms were proposed, and expert systems were widely used to solve domain-specific problems. Third wave: A breakthrough in deep learning theory in 2006 gave rise to the third wave of AI. In this stage, the internet, cloud computing, big data, AI chips, and other emerging technologies provide sufficient data services and computing support for the development of AI, and business model innovation (represented by "AI+") has also became increasingly mature as the AI industry has developed, greatly improving social productive forces (生产力) and profoundly affecting the structural transformation of existing industries.

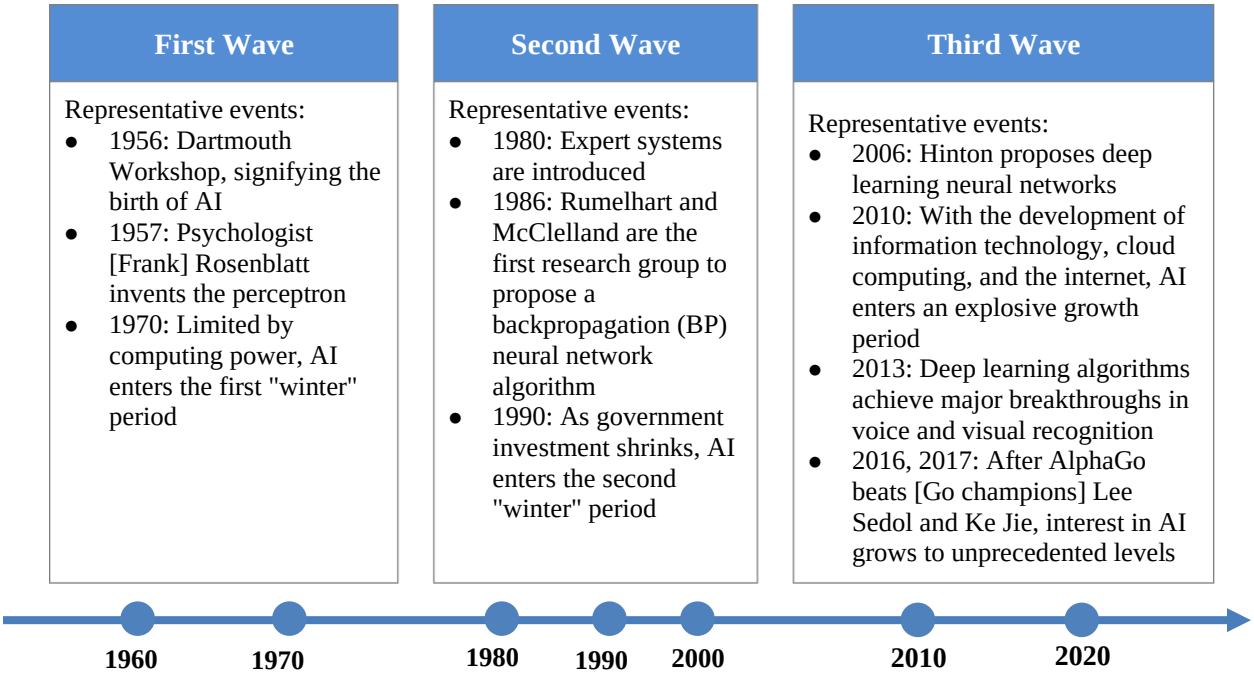


Figure 1-1 AI industry pattern—3 waves of AI development

Data source: Figure is from *Artificial Intelligence Industry Talent Development Report (2019–2020)*

The global AI industry has developed a relatively complete ecosystem, and a host of leading S&T innovation-oriented enterprises have emerged from the AI industry's basic layer, technology layer, and application layer.

(1) Basic layer: Provides computing power and data services support to the AI industry chain. Enterprises, represented by industry giants such as Amazon Web Services (AWS), Azure, Alibaba Cloud, Tencent Cloud, and Baidu Cloud, provide sufficient computing power resources for the development of AI; traditional chip giants NVIDIA and Intel, and domestic technology newcomers Cambricon, Horizon, etc., are dedicated to providing special chips for AI computing needs. In addition, there are also a great many companies in the data services field, such as Datatang and Speechocean domestically, as well as Saagie, etc., abroad.

(2) Technology layer: Provides general technical capabilities for the AI industry chain. The internet giants, represented by Google, Facebook, Alibaba, and Baidu, have used their capital and talent advantages to lay out comprehensive positions in AI-related technology fields earlier than others. At the same time, there are also a great many innovative companies working on niche technologies. Examples include iFlytek, which specializes in intelligent voice, SenseTime, which is dedicated to computer vision, and 4Paradigm in the machine learning field. Outside of China, companies such as Proxem and XMOS are also actively engaged in the practice and exploration of the natural language processing and intelligent voice fields, respectively.

(3) Application layer: Provides service users various kinds of specific applications, and products or services adapted to industrial application scenarios. At present, most of the world's innovative technology companies in AI fields are concentrated in this layer. Typical companies include Verdigris and Terminus in the field of smart buildings, Genetec and Uniview

in the field of smart security, and Flatiron and Infervision in the field of intelligent healthcare.

B. The Global Rise of AI Industrial Policies

After over 60 years of development, AI has a very broad range of coverage, and it has more complex and richer connotations than S&T fields generally. In recent years, AI data, algorithms, computing power ("compute"), and other ecosystem elements have become increasingly mature, but the digital economy and development of the smart manufacturing industry still face many unresolved practical problems, so the global AI industry will usher in a new round of strategic opportunities. In this context, the world's leading countries are paying close attention to and promoting AI research, and have developed national strategies and policies centered around developing the AI industry.

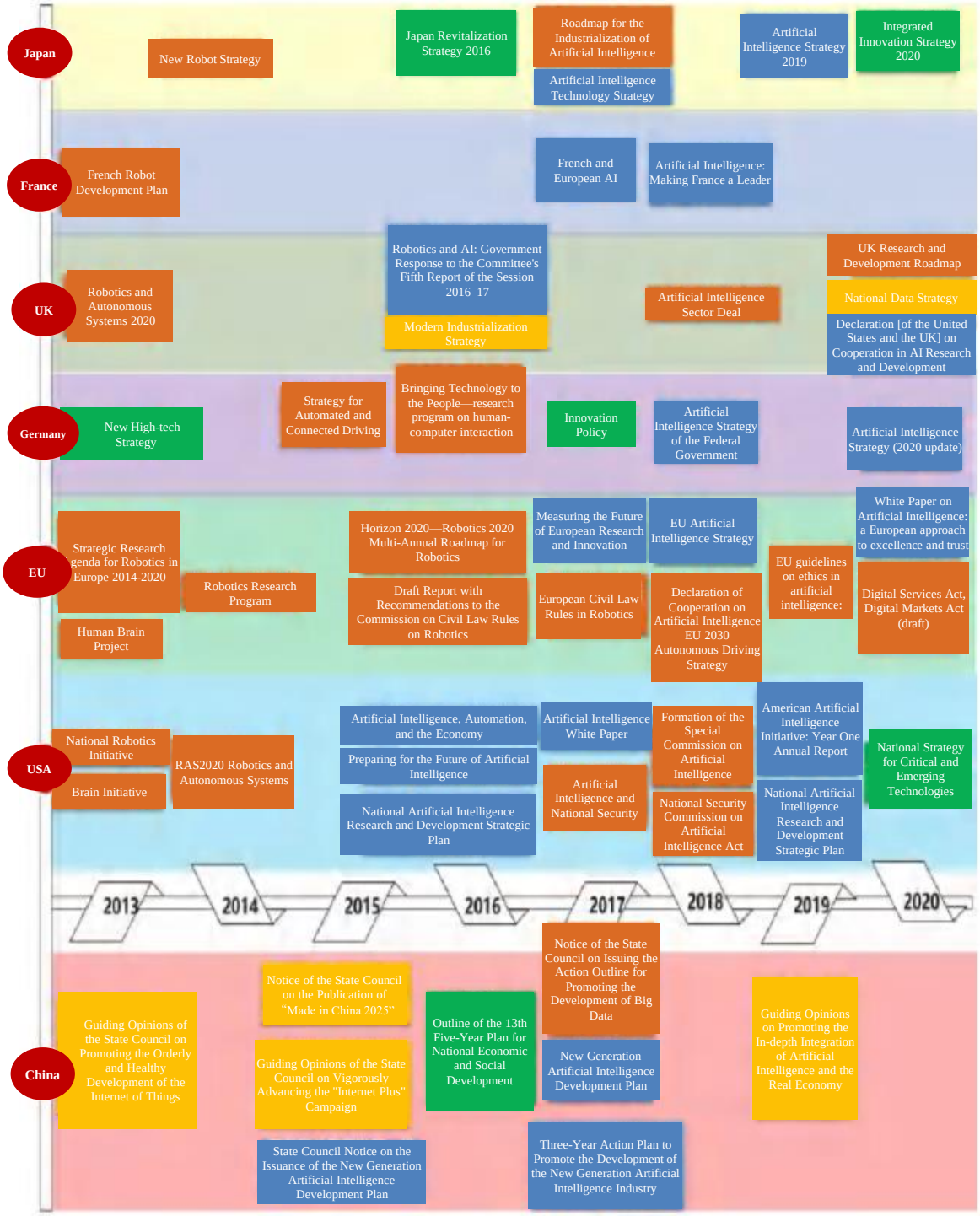


Figure 1.2 Global Artificial Intelligence Strategic Planning

Note: Green represents national-level grand strategies, blue represents overall AI industry strategies, orange represents AI industry segment strategies, and yellow represents other industry strategies for synergistic development with the AI industry.

International AI development strategies and policies are mainly divided into national-level grand strategies, overall AI industry strategies, other industry strategies for synergistic

development with the AI industry, and AI industry segment strategies. In terms of the strategic layout of different countries: China focuses on the synergistic layout at the strategic level, but lacks a strategy to guide the development of segments; the United States does complete planning of national top-level design and industry segments, but lacks a strategic layout for synergistic development with other industries; and the EU focuses on the strategic layout of AI industry segments.

(1) United States: Lay out a comprehensive AI policy system to achieve leadership in key areas and emerging strategic fields. Increase policy support for basic research, R&D areas, and applied research to consolidate leading positions in key areas of technology. In the field of AI R&D, the United States focuses on human-computer interaction, natural language processing, intelligent visual recognition, and big data analysis. In the AI applications field, the United States has set chips, computer hardware and software, the financial industry, and military and energy fields as the key directions to focus on, and the relevant policies released include the 2016 *National Artificial Intelligence Research and Development Strategic Plan*, *Artificial Intelligence, Automation, and the Economy (2016)*, *Preparing for the Future of Artificial Intelligence (2016)*, and the *Artificial Intelligence White Paper (2017)*.

Strengthen international cooperation and create an international environment that promotes support for AI development and innovation in the United States. The United States stresses cooperation with global allies in AI applications, and actively creates strategies to address opportunities and challenges of common interest, emphasizing the sharing among international partners of expertise that can be mutually beneficial, while advocating that trust should be promoted in international relations to foster economic growth and promote AI development and innovation. In September 2020, the U.S. and UK governments formally signed the *Declaration on Cooperation in AI Research and Development 2020* to promote cooperation between the two countries in AI development and to recommend priorities for AI planning.

Focus on the impact of AI on national security. In June 2020, three bipartisan bills were introduced in the U.S. Congress, and the *Army Artificial Intelligence Act* in particular further raised the importance of AI in overall defense deployment.

(2) Europe: Fully exploit manufacturing advantages, and use AI and other related technologies to promote intelligent upgrading of manufacturing and related fields

The EU's focus on AI applications is more refined. Unlike the all-round leadership of the United States, the EU hopes to leverage its advantages in the manufacturing, industrial, automotive, and other fields, and use AI technology to strengthen and upgrade industries. The EU has released policies or plans such as the *Strategic Research Agenda for Robotics in Europe 2014-2020*, the *Draft Report with Recommendations to the Commission on Civil Law Rules on Robotics (2016)*, the *European Civil Law Rules in Robotics (2016)*, *Measuring the Future of European Research and Innovation (2017)*, and the *Horizon 2020—Robotics 2020 Multi-Annual Roadmap for Robotics*. Germany in particular has put forward strategies related to the development and application of AI around the Internet of Things, cloud computing, big data, smart cities, autonomous driving, smart manufacturing, and other fields, and published the *New High-tech Strategy (2013)*, *Bringing Technology to the People—Research Program on Human-computer Interaction (2017)*, *Decision of the Federal Ministry of Education and Research on the Creation of a 'Learning System' Platform (2017)*, and the 2017 "Innovation Policy," as well as *Discussions*

on Artificial Intelligence Strategy carried out with France in 2018. Centered around the "Modern Industrialization Strategy," the UK is promoting the development and layout of 5G networks, new energy, new materials, equipment manufacturing, and robotics and AI. Its published policies include the *Modern Industrialization Strategy (2016)*, *Developing Artificial Intelligence in the UK (2016)*, *Robotics and AI: Government Response to the Committee's Fifth Report of the Session 2016–17*, and *Robotics and Automated Systems (2020)*.

(3) Japan: Vigorously promote AI applications and digital transformation in well-positioned (优势) industrial fields

Combining its strong advantages in traditional machinery manufacturing and robotics, Japan has established a comprehensive set of AI R&D promotion mechanisms and industrial development policies in the fields of robotics, healthcare, and social services, and is accelerating the digital transformation of related fields. The AI policies issued in Japan include the *Japan Revitalization Strategy (2016)*, *Artificial Intelligence Technology Strategy (2017)*, *Artificial Intelligence Strategy 2019*, and *Integrated Innovation Strategy 2020*. The *Artificial Intelligence Strategy 2019* points out that Japan has three major mission objectives for AI technology R&D and industrial development: (1) lay the foundation for future development; (2) build the foundation for social applications and industrialization; and (3) develop and apply AI ethical norms.

(4) China: Continue to strengthen the deep integration of AI and the real economy

China has accumulated rich experience in fields like AI algorithms, applied basic research on AI, 5G, and autonomous driving, and has initially formed a synergistic "AI + whole production chain" layout. Since 2013, China has issued *Guiding Opinions of the State Council on Promoting the Orderly and Healthy Development of the Internet of Things*, *Notice of the State Council on Issuing 'Made in China 2025*,' *Guiding Opinions of the State Council on Vigorously Advancing the 'Internet Plus' Campaign*, *Notice of the State Council on Issuing the Action Outline for Promoting the Development of Big Data*, and *Outline of the 13th Five-Year Plan for National Economic and Social Development*. In 2017, which has been dubbed "AI year one" by the media, China issued the *State Council Notice on the Issuance of the New Generation Artificial Intelligence Development Plan*, which provides a guiding plan for the development directions and key fields of China's AI industry in the future.

Elsewhere, Norway released its *National Strategy for Artificial Intelligence (2020)*, Saudi Arabia released the *National Strategy for Data and AI (2020)*, and emerging countries in the AI field, such as Singapore, Denmark, the Netherlands, and Russia, are also actively formulating national strategies for AI and accelerating AI industry development. In general, major countries around the world all have policy support in the field of AI, from national strategies to strategies for the industry and sub-sectors, and countries have launched competition and cooperation in different fields. One can predict that, in the future AI competition system, whoever takes the lead in forming a perfected whole-production-chain advantage will gain the lead in AI.

C. Competition Is Intensifying in the Global AI Industry

The COVID-19 epidemic has had a major impact on socio-economic and industrial development, but has not slowed down countries competing to lay out the S&T high ground. Global technology competition remains in a state of increasing intensity, prominently reflected in two ways: The first is the introduction of new S&T development strategies to accelerate digital

transformation. In October 2020, the U.S. government released the *National Strategy for Critical and Emerging Technologies*, vowing to promote and protect the United States' competitive advantages in areas such as biotechnology, AI, energy, quantum information science, communications and network technology, semiconductors, and military and space technology. After coming to power in September 2020, former Japanese Prime Minister Yoshihide Suga viewed 5G networks as one of the pillars of economic growth, and invested hundreds of millions of dollars in building 5G and post-5G technologies. The UK Ministry of Defense released its *Science and Technology Strategy 2020* to strengthen understanding of the future technology landscape, take aggressive action to gain first-mover advantage, and lay the foundation for next-generation military capabilities. During the same period, strategic measures were also introduced in EU countries, Japan, Russia, China, and other countries. The second is the use of AI as a key element in S&T development. Germany plans to increase its investment in AI from 3 billion euros to 5 billion euros by 2025, in order to make Germany Europe's main driver of future AI technology. The EU released the *White Paper on Artificial Intelligence*, which aims to promote Europe's innovation and development in the field of AI. South Korea released a new policy on AI, with plans to invest 76 trillion won [$60 billion] to promote cross-industry use of 5G networks and AI technologies. At the same time, competition among countries is also reflected in competition over the right to set standards for technology norms, with the UK Ministry of Defense reporting that it will work with allies and partners to draw up standards and norms affecting the application of emerging technologies, such as ethical frameworks, technology protection, and interoperability, thereby helping the UK to take a leadership position. The Trump administration asked the National Institute of Standards and Technology (NIST) to develop and publish standards and guidance to resolve issues related to the development, management configuration, and repair of Internet of Things (IoT) devices.

Currently, major industrial countries around the world are focusing on their AI industry layouts, and the level of AI industry development has become an important indicator for measuring the strength of a country's S&T innovation. In 2018, China released the *New Generation Artificial Intelligence Development Plan*, which proposed that "by 2030, China will become a major world center of AI innovation." In 2019, a report released by Deloitte entitled *The Future is Already Here—Global AI Innovation, Integration, and Application Cities and Outlook* indicates that the size of the world AI market will exceed U.S. $6 trillion by 2025, and the AI industry will become the most important driving force for the development of the global digital economy. Talent, data, and system architectures are the three major asset elements indispensable for high-quality AI industry development. The quantity and quality of AI talents in particular will directly affect global data collection and processing ability, as well as the applicability and extensibility of the underlying architecture. Therefore, for the global AI industry, its core asset is high-quality talent, and the scale, structure and quality of AI Talent Training in different countries will determine the future competitive landscape in AI.

II. Analysis of the Current Situation in Global AI Talent Development

A. Global AI Talent Competition Strategies

At the core of global AI competition is competition in talent (quantity and quality), and the key is competition in talent training ability. In order to seize the first-mover advantage in the new

round of technology competition, as of December 2020, 39 countries and regions around the world had formulated AI strategic policies and industrial planning documents,[1] and generally made talent cultivation a strategic priority. With regard to the AI talent competition strategies of different countries, the United States comprehensively promotes a diversified AI talent pool to maintain technology leadership; Japan is relying mainly on its strong industries to promote the construction of a multi-level AI talent training system in phases; the UK is focused on enhancing the participation of universities in AI talent training; and Canada's strategic focus is on building a complete talent ecosystem to attract, cultivate, and retain talent.

1. United States

The United States has formally elevated AI industry development to the level of national strategy and regards AI talent cultivation as a strategic priority. With the goal of "comprehensively developing a diverse and ethically literate AI team and maintaining U.S. leadership,"[2] it has deployed a systematic AI talent competition strategy from top to bottom. Specifically: It focuses on building an AI education system with universal coverage across all academic levels. And while actively promoting the cross-disciplinary development of AI, and improving advanced AI degree recruitment and retention plans so as to advance the construction of AI education at the higher education level, it is also focusing on the popularization of AI education at the K-12 level, and helping U.S. workers obtain AI-related skills training by developing apprenticeships in science, technology, engineering, and mathematics (STEM) fields and developing lifelong learning programs. Creating a good AI ecosystem and attracting an inflow of international talent: By building close industry-academia-research institute (产学研) partnerships, a relatively lenient legal environment, and better institutional safeguards, it has developed a high-quality AI ecosystem, led by industry giants such as Google, Microsoft, Amazon, Facebook, and IBM, which attracts a global inflow of companies, institutions, and top AI talent. For example, most of the world's top ten AI scientists listed by EO Intelligence (亿欧智库) work in American research institutions or companies. Actively exploiting the leading and coordinating role of the government in AI talent training: The U.S. government is committed to building long-term communication mechanisms with participation by multiple parties, including the government, universities, research institutions, and enterprises. It also actively explores legislative improvements, policy incentives, and mechanism innovation. For example, the *National Artificial Intelligence Research and Development Strategic Plan: 2019 Update* requires the federal government to take the initiative in opening up training data methods and data standards, and the open sharing of data and open sourcing of programming provides a platform to support talent training. At the same time, AI is listed as a priority funding area in the federal Scholarship for Service (SFS) program, which provides material assurance to promote faculty development in related disciplines, as well as motivation to participate in AI training.

2. Japan

Japan's AI development strategy is based on the new era development concept of building a super-smart "Society 5.0." Following the guiding principle of combining with well-positioned industries, it hopes to take advantage of Japan's long-term strengths in machinery manufacturing and robotics, and use robotics, healthcare, and social services as breakthrough points. By improving AI development, it seeks to accelerate the digital transformation of related fields and cultivate talent in “smart” fields (智慧人才), and thereby solve national problems in healthcare, elder care, education, and business.[3]

In terms of talent training, Japan has proposed the development goal of "cultivating 250,000 AI talents each year, and becoming the world's top AI talent country calculated relative to population base." To achieve this goal, the *Artificial Intelligence Strategy 2019*, released in 2019, proposes a multi-level, hierarchical AI talent cultivation system that covers building [scientific] literacy education, application-level basic education, and expert talent cultivation, so as to lay a solid foundation for promoting and popularizing the social application of AI and increasing the citizenry's acceptance of the AI era. At the same time, Japan plans to promote AI talent training in three stages: In the first stage, rapid technological catch-up is to be achieved by recruiting outstanding talents and attracting excellent researchers from home and abroad to study in Japan. In the second stage, excellent entrepreneurs and start-ups are cultivated to promote the industrialization of R&D results and create new sources of economic growth. Toward this end, Japan plans to focus on promoting industry-academia cooperation and improving curriculum development and the layout of related academic disciplines, so as to develop the relevant qualities of students in a targeted manner. In the third stage, large numbers of AI grassroots practitioners are to be trained through innovative worker training methods, building up a large basic labor force for AI industry jobs such as assembly and monitoring, and thereby achieving talent structure optimization and promoting the AI industry's overall development.[4]

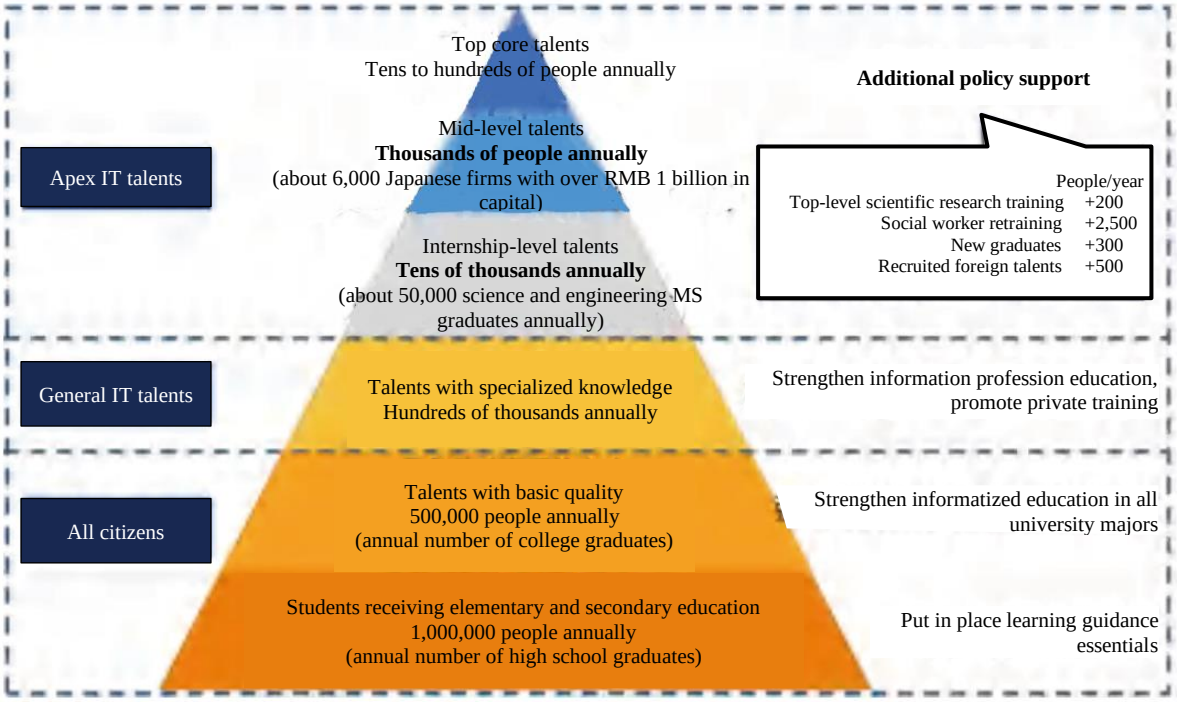


Figure 2.1 Japan's hierarchical AI talent cultivation system

Data source: Li Zhe, Li Juan, Li Zhangjie, Zeng Dan, "A study on the strategy and talent training model of artificial intelligence in Japan [J], *Modern Educational Technology*, 2019, 29(12): 21-27.

3. United Kingdom

As the birthplace of Alan Turing, the "father of computer science" and "father of AI," the UK has a solid AI foundation. The report *Developing Artificial Intelligence in the UK* published in 2017 proposes the development goal of "developing the world's most suitable country for developing and deploying AI, starting from four aspects: data, technology, research, and policy

openness and investment."

In terms of talent training, in order to consolidate its first-mover advantage in the field of AI, the UK has proposed a development strategy of "combining higher education with AI technology," encouraging universities to actively participate in AI field knowledge updating, property rights, and talent training. Specific measures include: (1) Actively laying out AI higher education development. The UK has invested 100 million pounds [$120 million] in higher education to establish AI scholarships, create AI degrees, and offer AI courses. In addition, to achieve the goal of increasing the annual number of doctoral students in AI and related disciplines by at least 200, the UK has adopted a master's-doctoral degree integration training model, and encourages students from different disciplines to pursue further studies in AI. (2) Integration of science and education, relying on national strategic laboratories to promote talent training. The UK has created the national-level Alan Turing Institute and an Engineering and Physical Sciences Research Council (EPSRC) AI institute. These top laboratories will collaborate with functional departments such as EPSRC, the Science and Technology Facilities Council, and the Joint Information Systems Committee, as well as renowned universities such as Oxford University, Cambridge University, Imperial College, and University College London to jointly focus on AI development and talent training. (3) Industry-education integration and establishment of a special master's degree in AI. In addition to encouraging university researchers to set up spin-off companies and promoting the standardization of intellectual property transfer, the UK government, industry, and universities have committed to jointly funding the creation of 16 AI education centers across the country, and will also establish the first industry-funded AI master's degree program, which will include workplace internships, setting a precedent for three-way joint investment in education.[5]

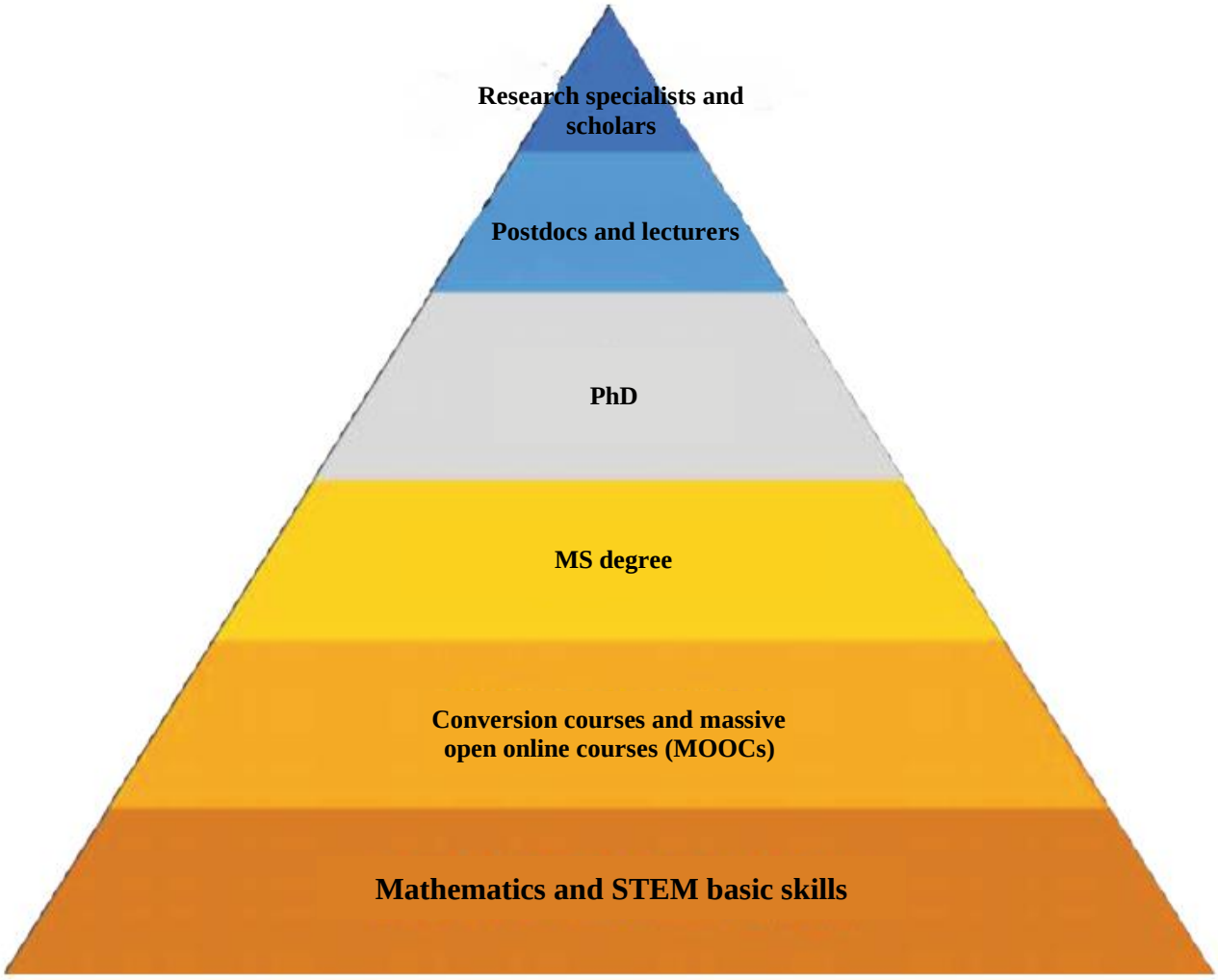


Figure 2.2 The UK's AI Talent Training system pyramid

Data source: Liu Jin and Zhong Xiaoqin, "A comparative policy study of global AI talent training: The case of China, the United States, the UK, and Canada[J]," Chongqing Higher Education Research, 2021, 9(02): 39-50.

4. Canada

Canada has consistently held a leading international position in AI talent education, having some of the world's top deep learning talents such as Geoffrey Hinton, Richard Sutton, and Yoshua Bengio. In 2017, Canada released the *Pan-Canadian Artificial Intelligence Strategy*, the world's first national strategic plan for AI, announcing $125 million [U.S. $96 million] in government funding to support the Canadian Institute for Advanced Research (CIFAR) in implementing the CIFAR AI Chairs Program. The strategy aims to "achieve large-scale training of AI researchers and graduates," "establish three AI research centers," "develop global thought leadership in the economic, ethical, policy and legal implications of AI development," "support the national AI research community," and other important development goals.

In terms of talent training, although Canada has the third largest AI talent pool in the world and ranks first in the world in terms of talent density, it is also plagued by a large outflow of AI research and industrial talent to the United States. The basic reason is that Canada lacks an

attractive AI talent ecosystem like that of Silicon Valley. Having fully recognized this problem, Canada plans to further increase investment in AI research, hoping to build an education-focused AI talent ecosystem to resist the "talent siphoning" effect of Silicon Valley and help Canada become an AI power. For example, in response to the brain drain dilemma, Canada is actively promoting a top talent strategy to improve the quality of top talent, and in order to increase the penetration rate of AI technology among all Canadians, it has organized the "AI4Good" national training program and opened Institute for Data Valorization (IVADO) international summer school sessions and courses.[6][7]

Table 2.1 AI talent competition strategies in four countries: The United States, Japan, the UK, and Canada

Country	AI talent competition strategy
United States	Actively utilize government's leadership and coordination role in AI talent training, focusing on building an AI education system that covers all educational levels and the whole populace, while also paying attention to developing the AI ecosystem, and ultimately building a diversified and ethical AI team to maintain the United States' leading position in technological innovation.
Japan	Centered around the new era development concept of building a super-smart "Society 5.0," follow the guiding principle of combining with well-positioned industries, using robotics, healthcare, and social services as breakthrough points; by building a multi-level hierarchical talent cultivation system of literacy education, application-based education, and expert talent cultivation, promote digital transformation and training of talent in "smart" fields in related areas in three stages. This will then serve to solve national challenges in the fields of elder care, education, and business.
United Kingdom	Following a development strategy of "combining higher education and AI technology," actively promote science-education integration and industry-education integration by relying on national laboratories to promote talent cultivation and establishing special AI master's degrees; increase enthusiasm of universities for participating in AI talent training, and increase the quality of AI talent training in universities.
Canada	By creating an AI talent ecosystem with talent education at its core, reduce the brain drain and help Canada become an AI power.

B. Scale and Structure of Global AI Talent

1. Talent supply

Thanks to the continuous enrichment and maturation of AI industry ecosystems, global AI talent is growing rapidly. The *2018 China AI Development Report* shows that, as of 2017, the total input of international AI talent had reached 204,575 people, concentrated in North America, Western and Northern Europe, East Asia, and South and West Asia. In terms of distribution by country, AI talent is concentrated in a few countries. The top ten countries account for 61.8% of the total AI talent input, with the United States being dominant, having a cumulative 28,536 people and accounting for 13.9% of the world total. China's total AI talent input ranks second, accounting for 8.9% of the world total and representing 65% of the United States' total; India, Germany, and the UK were ranked third, fourth and fifth, respectively, with 17,384, 9,441 and 7,998 talents. From an urban distribution perspective, the cumulative talent in the top five-ranked cities of the United States, China, India, Germany and the UK, as a proportion of the country's total, was 10.5%,

20.0%, 149%, 173% and 23.3%, respectively.

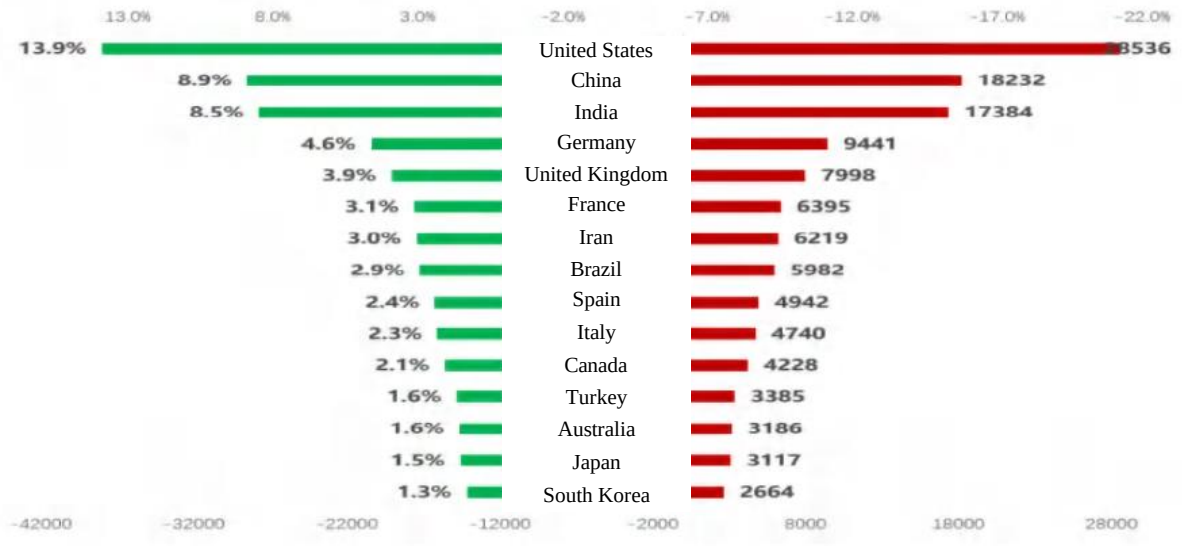


Figure 2.3 International AI talent training data

Data source: *2018 China AI Development Report*

(1) Scientific research talents

In terms of the number of students, according to the *2017 Global AI Talent White Paper* published by Tencent Research Institute, as of 2017 there were 367 higher education institutions ("universities") around the world that had established AI research programs, of which 168 were in the United States, accounting for 45.7% and ranking first in the world. The *Global AI Talent Mobility Report 2019* shows that U.S. universities produce 44% of the world's AI PhDs, greater than the combined total of the EU (21%) and China (11%), and this largely shapes the United States' advantage in AI research talent.

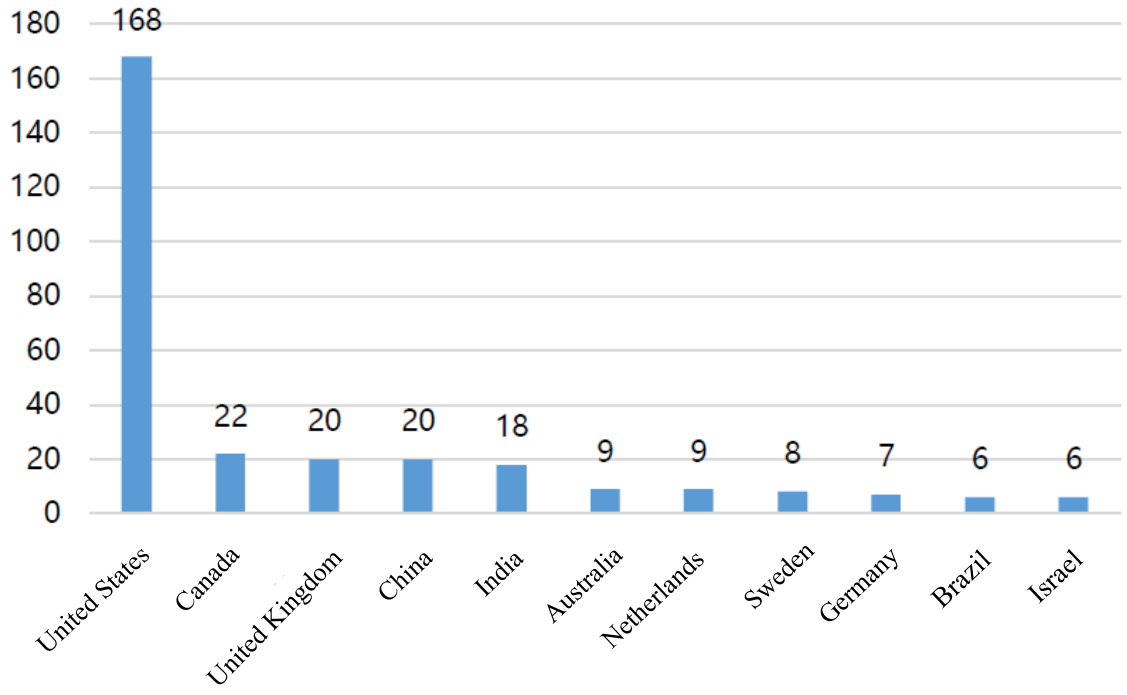


Figure 2.4 Global AI college and university numbers

Data source: *Tencent Research Institute: 2017 Global AI Talent White Paper*

With regard to the number of scholars, the *2021 Talent in "Smart" Fields Development Report* (《智慧人才发展报告（2021）》) indicated that the number of scholars in the AI field totaled 155,408 in 120 countries, but were concentrated mainly in North America, Europe, and East Asia. In terms of the distribution of high-level scientific research talents, the United States holds an absolute leadership position, accounting for over 50%. A list of the world's 2,000 most influential scholars, published by Tsinghua University, showed that the United States held the world number one spot with 1,128, followed by China (171), Germany (110), the UK (83), and Canada (63). This indicates that the United States continues to lead the world in top scientific research talents.

Figure 2.5 Global distribution of AI scientific research talent

Data source: *2021 Talent in "Smart" Fields Development Report*

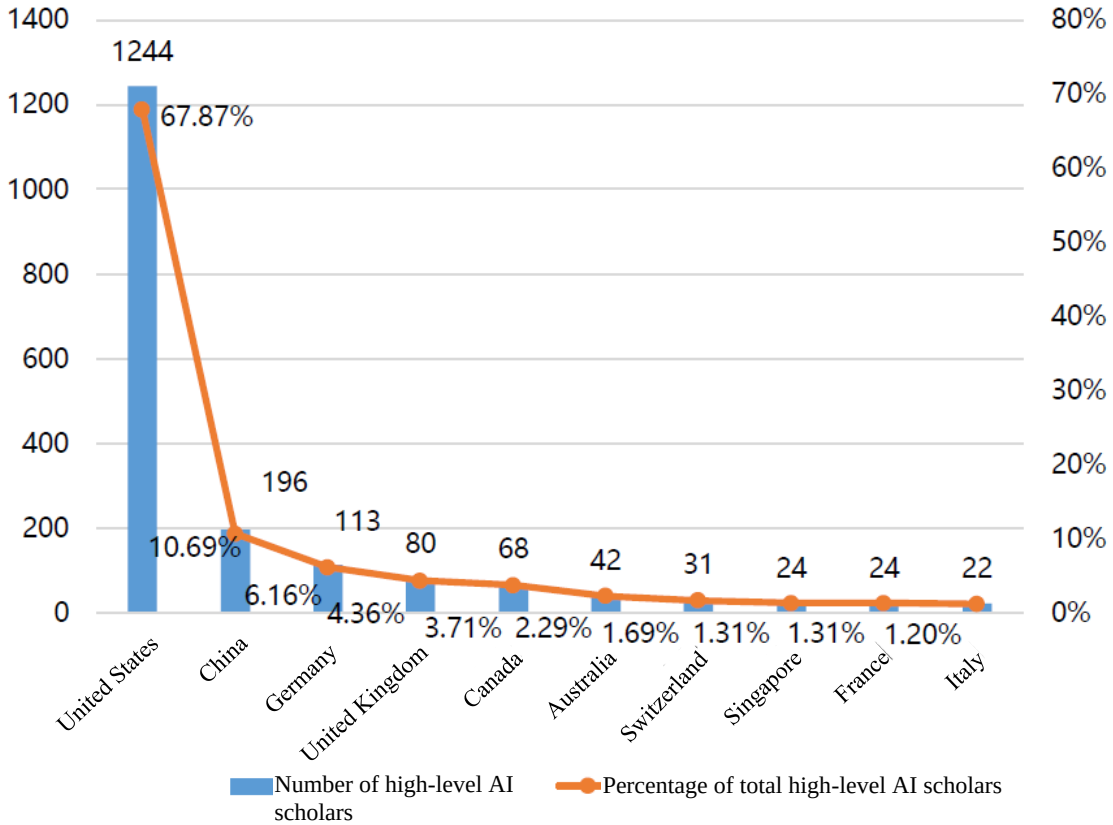


Figure 2.6 Distribution of high-level AI scholars

Data source: *2021 Talent in "Smart" Fields Development Report*

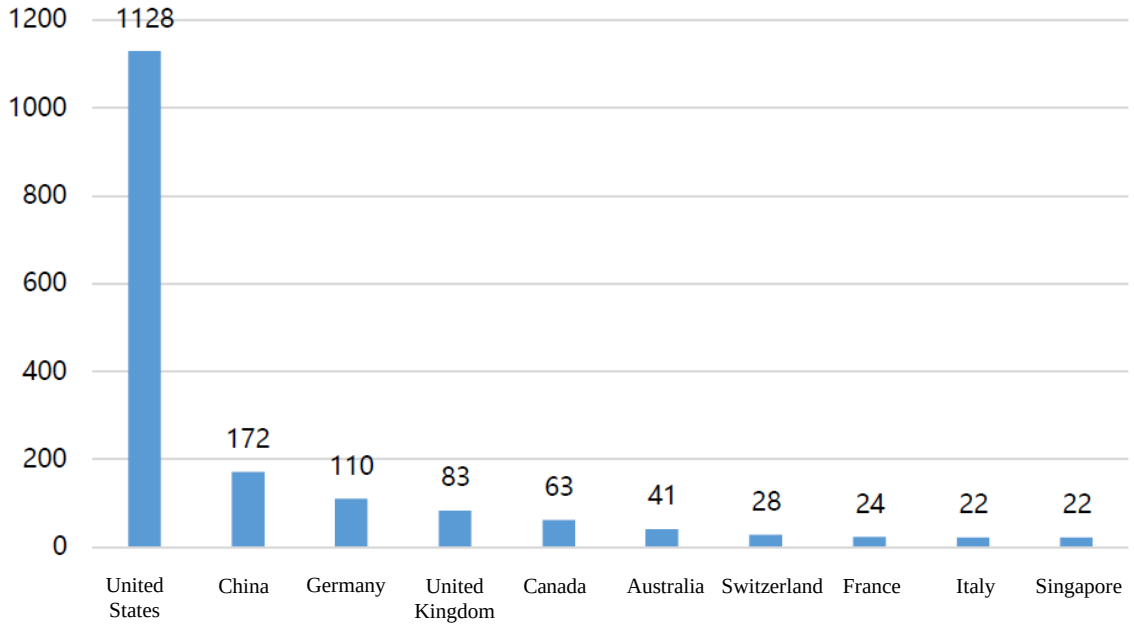


Figure 2.7 Global distribution of the 2,000 most influential AI scholars

Data source: *2021 Talent in "Smart" Fields Development Report*

(2) Industry talents

In early December 2017, the *2017 Global Artificial Intelligence Talent White Paper*, released by Tencent Research Institute in conjunction with BOSS Direct Hire (BOSS 直聘), showed that the total number of global AI talents was then about 300,000, including about 200,000 industry talents, mainly distributed among giant AI companies in various countries, and these technology giants were concentrated in North America, Asia, and Europe (accounting for more than 98%). The *2018 China AI Development Report* released by Tsinghua University ranked the companies employing the most AI talent based on AI papers and patent records, and found that half of the top 20 companies were established in the United States. Those ten U.S. companies on the list had a combined total of 1,623 AI talents, compared to six companies in the EU employing 522 AI talents, and only one Chinese company, Huawei, employing 73 relevant talents, reflecting the fact that the United States likewise has an overwhelming dominant position when it comes to industry talent. In addition, as can be seen from a study conducted by Tencent Research Institute in 2017 on 81 founders of the world's top AI companies, the United States holds the lead with 43 of the top industry talents, followed by China with 17 and the United Kingdom with six. It is worth noting that twenty of the founders are ethnic Chinese (华人), accounting for about one-fourth of the total, which reflects the important role played by Chinese in the AI industry.

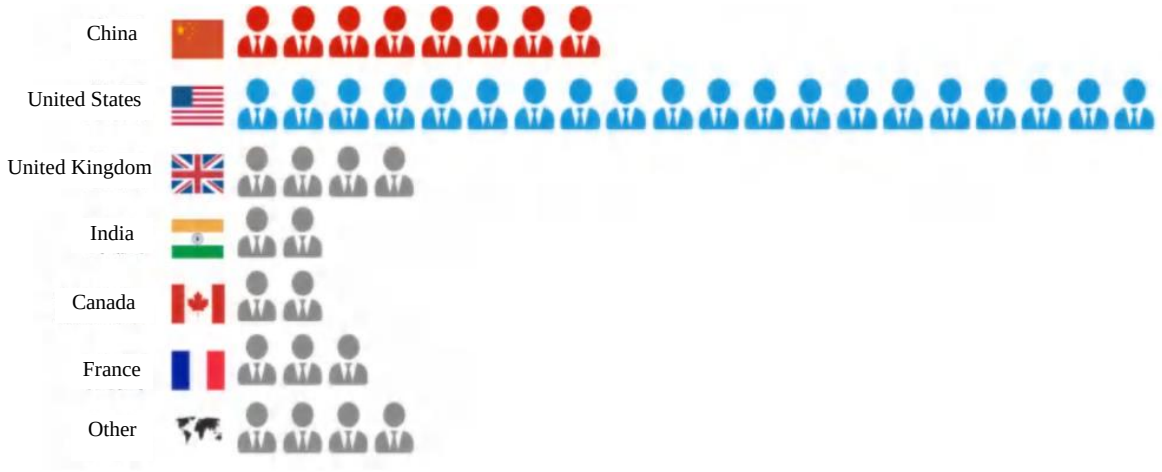


Figure 2.8 Distribution of the founders of leading AI firms by nationality

Data source: *2017 Global AI Talent White Paper*

2. Talent demand

The AI industry's rapid development has driven rapid growth in the demand for talent. According to the *2020 AI Talent Report* released jointly by TalentSeer and AI talent community platform Robin.ly, demand for AI talent grew by an average of 74% annually from 2016 to 2019. From a country perspective, the *AI Jobs* report put out by UiPath in 2018 shows that there are certain AI job gaps in all countries, with China in first place with 12,113 job vacancies, followed by the United States with 7,465 vacancies, and Japan with 3,369. In addition, the UK, India, Germany, and other countries are also facing AI talent shortages at the same time, reflecting the fact that countries around the world are currently facing a general imbalance between the supply and demand of AI talent.

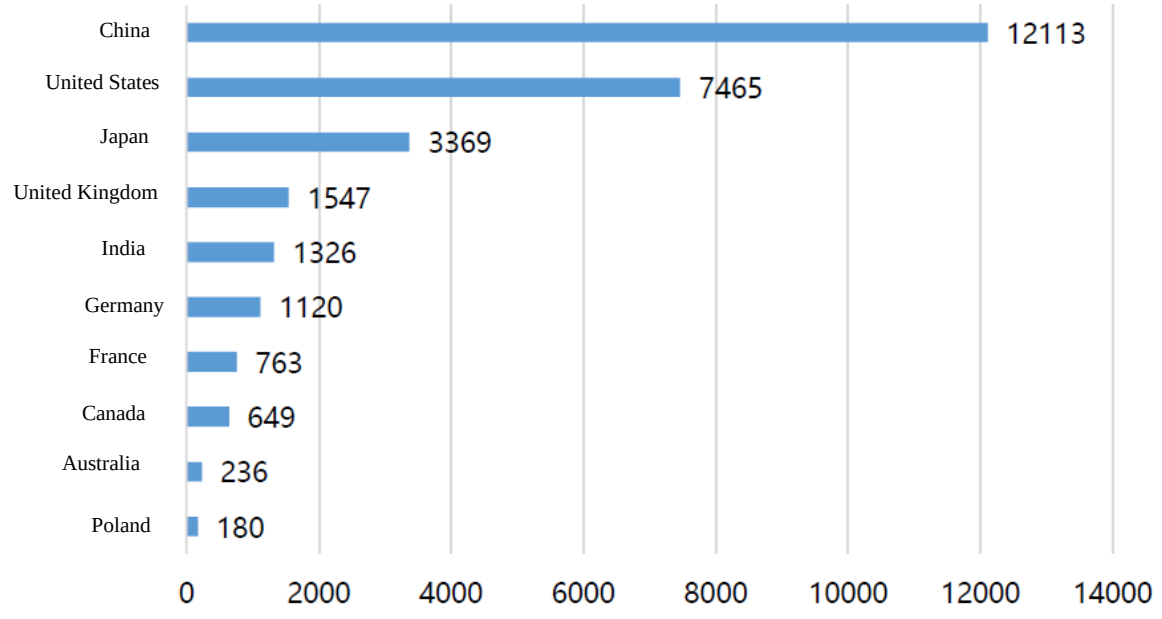


Figure 2.9 Global job demand for AI positions

Data source: Taken from *EO Intelligence: 2020 Global AI Talent Training Research Report*

With regard to types of talents, the *TalentSeer 2020 AI Talent Report*'s statistical results show that demand by AI companies in 2019 was highest for AI algorithm staff, with a demand level[1] of 80%, followed by AI research staff and platform architecture staff (55%), then data staff and hardware staff.

Table 2.2 Demand by AI companies for different types of talent in 2019

Type of staff	Specific positions involved	Demand level
AI algorithm staff	Deep learning and machine learning engineers	80%
AI research staff	Machine learning (ML), computer vision (CV), and natural language processing (NLP) research institute staff	55%
Platform architecture staff	Full stack (全栈), back end, security, and development operation engineers	55%
Data staff	Data scientists and engineers	35%
Hardware staff	Embedded systems and hardware engineers	35%
Product team staff	Product managers, back end engineers, user experience specialists	25%
Business team staff	Business development, marketing, legal, and sales staff	15%

Data source: Taken from *EO Intelligence: 2020 Global AI Talent Training Research Report*

In order to meet talent demand, nearly all tech giants have designed competition strategies targeted at AI talents. For Column 2.1, Google, Facebook, and Apple were selected in order to introduce several important measures companies have taken to bolster their own ranks of AI talents.

[1] Translator's note: The term "demand level" (需求度) apparently refers to the percentage of companies that have an urgent need to hire employees with a particular skill set.

Column 2.1 AI talent competition strategies of tech giants

1. Google: Ninja Program

In order to expand the number of internal AI elite talents and make AI a regular technology that everyone can master, Google has developed an AI training program—the "Ninja Program." Based on the advantages of its own large team of engineers, the program aims to increase the prevalence of AI technology training in different departments. For example, in the "Machine Learning Ninja" program, Google selects elite members from various departments through an "Ender's Game" approach, and trains them in machine learning for six months. Guided by mentors, these people participate in some of the AI projects, and from this beginning go on to master a large amount of machine learning knowledge. Eventually, the knowledge they learn is applied to improve the intelligentization (智能化) of the products in their departments.

2. Facebook: AI West Point

Compared with Google, which puts the focus of AI Talent Training on technology diffusion and emphasizes having as many internal employees as possible understand and apply AI technology, Facebook pays more attention to the improvement of training quality. Toward this end, Facebook AI Academy launched a systematic AI training course covering the whole process from technical training to project practice. The course is divided into two parts. The first part requires learners to participate in a practice-oriented deep learning course designed by Larry Zitnick, one of the heads of Facebook AI Research (FAIR) laboratory, together with other top experts. The course consists of six hours during which participants learn directly from FAIR experts about academic theory, including deep learning fundamentals, convolutional neural networks/recurrent neural networks (CNN/RNN), and augmented learning, and finally apply the academic theory to the practical development of deep learning models. The second part of the program requires participants to participate in an AI immersion program to gain deeper hands-on experience. The course requires engineers to work at FAIR for 1-2 years participating in real-world research projects with top industry experts. After "graduation," engineers apply their knowledge in other technical teams, thus spreading AI knowledge throughout the enterprise.

3. Apple: Stepping up acquisitions to achieve rapid catch-up

Compared with Google and Facebook, Apple is a latecomer to AI talent training system construction, so Apple has stepped up its corporate acquisitions in an attempt to catch up rapidly. According to GlobalData transaction figures, Apple, Google, Microsoft, and Facebook made 60 acquisitions in the field of AI technology from 2016 to 2020. Apple led the AI company acquisition race, having acquired 25 AI companies, including Silk Labs and Turi. Through frenzied acquisitions, Apple has quickly filled out its ranks of engineers and product talents with expertise in machine learning, computer vision, autonomous driving, and other important AI areas.

C. Global AI Talent Development Trends

In terms of AI talent strategy, promoting the development and application of AI has become the consensus approach of the world's major economies, and the focus of strategic competition has gradually turned to AI talent training systems that span all academic levels and provide universal coverage. In order to seize the "high ground" in talent, one country after another has issued incentive and assurance policies, and the overall trends have been to constantly ramp up support for talent training, expand the coverage of AI education, and attach ever greater importance to attracting international talent. However, due to differences in resource endowments and development goals, each country has its own focus in terms of AI talent strategy cycle, development priorities, and the layout of AI fields. In particular, the United States is focused on building a diversified talent pool and emphasizes the need for the federal government to play a major role in talent training. The UK has taken raising higher education participation rates as one of the main ways to promote AI talent, and it has taken a number of characteristic measures in science-education integration and industry-education integration. Japan mainly relies on its long-term advantages in robotics and other areas to carry out AI talent training. And Canada sees its main task as building a complete talent ecosystem.

Global AI talent is growing fast, thanks to the continuous maturation of the industrial ecosystem. The rapid development of the AI industry has significantly increased demand for relevant application and research-oriented talents. There is still a huge gap overall between the supply of talent provided by current education systems and the demand for talent. According to statistics, there are about 20,000 graduates in the AI field worldwide every year, which falls far short of meeting the market's demand for millions of talents. In addition, due to the relative lag in the output of college talent, high knowledge and technology barriers in the AI field, and sizable cross-disciplinary difficulties, the talent gap may well continue to grow in the short term, and the pressure on supply will become more and more pronounced.

As regards AI talent structure, the overall situation in AI talent pool construction is that the United States is "leading," China is "keeping pace," and the UK, Germany, Japan, Canada and other countries are "following." The United States has a leading position in the number of scientific and industrial talents, basic talents, and top talents. The UK is in the forefront of training scientific talents, with Oxford, Cambridge, the Alan Turing Institute, and other research and higher education institutions boasting deep roots in the field of AI and machine learning. Japan has a leading position in mechanical manufacturing and robotics, and has established talent advantages in its traditional strengths—mechanical engineering and robotics. And China's excellent AI talent is concentrated in universities and research institutions, while the talent gap in industry is relatively large. Countries generally attach great importance to the role of universities in developing research-oriented talents. Accelerating the construction of AI disciplines and establishing AI-related master's and doctoral degrees have become the most direct ways for countries to cultivate AI talents. As for application-oriented talents, major AI companies generally face a talent gap. The talent gap for technical positions and research talents is far greater than that for practical skills positions. There is an especially urgent need to solve the supply-demand imbalance in the areas of AI algorithms, basic research, and platform architecture. To fill these talent gaps, major tech giants are strategically monopolizing global AI talent at an unprecedented speed and scale.

In terms of AI talent quality, the United States holds the overall leading position in the

construction of top AI talents, with more than 50% of the global total of high-level research talents and more than 50% of the top AI companies' founders. With respect to reserves of top AI talents, nearly half of the universities currently offering AI research programs are located in the United States. These universities have produced 44% of the world's AI PhDs, providing the United States with a future competitive advantage. The UK, Canada, and other developed countries also rank among the world's top countries in talent training, but as competition among U.S. tech giants has intensified, these countries have suffered to varying degrees from crises in the form of "dramatic losses of top AI talent." In China, the total number of AI talents has been increasing steadily in recent years, but there is still a definite gap with the United States, the UK, and other developed countries in the area of high-end AI talents, especially top basic research talents and application scenario top talents who can integrate AI technology development with the industrial system. In response to this widespread demand, Baidu has proposed the goal of "training 5 million AI talents in the next 5 years" to further boost the competitive strength of China's AI talent pool.

III. Main Models of AI Talent Training in China and Their Problems and Shortcomings

The Ministry of Education's *Artificial Intelligence Innovation Action Plan for Institutions of Higher Education* pointed to the necessity of strengthening cooperation between universities and local governments, enterprises, and scientific research institutes, accelerating the conversion and application of S&T achievements in the field of AI in key industries and regions, and enhancing the ability of universities to serve major national strategies, regional innovation and development, economic transformation and upgrading, and to help secure the people's livelihoods.[8] Universities and enterprises are the two main players in AI talent training, and play key roles when it comes to AI talent reserves.

A. Current Supply-Demand and Distribution of AI Talent in China

1. Current AI Talent Training Situation

In 2019, the Ministry of Human Resources and Social Security joined two other ministries in releasing the *Analytical Report on Current Employment Prospects for Artificial Intelligence Engineers and Technicians*, which pointed to a serious imbalance between supply and demand: According to estimates, the current shortage of AI talents in China is more than 5 million, and the domestic supply-to-demand ratio is 1:10. If talent training is not strengthened, the talent gap will exceed 10 million by 2025. To address the real problem of serious AI supply-demand imbalance, China's universities are actively and quickly laying out construction of AI academic disciplines, and there has been a marked rise in the number of universities offering AI majors. According to statistics, the number of universities approved to open new AI major programs in 2019 increased by more than 400% compared with the previous year. In February 2020, there were 180 universities nationwide in the first batch to obtain qualifications for establishing AI majors, which represented an increase of 414% compared with 35 in 2018. In February 2021, the official website of the Ministry of Education published the *Results of Filing and Approval of Undergraduate Majors in Ordinary Institutions of Higher Education in 2020*. AI major programs at 130 universities were approved, further reflecting the sharp rise in the popularity of AI majors. In terms of building quality, Table 3.1 shows the top 20 universities in the AI field in mainland China in

the 2020-2021 CSRankings. Among those listed, Tsinghua University, Peking University, the Chinese Academy of Sciences (CAS), Shanghai Jiao Tong University, Zhejiang University, Nanjing University, and Harbin Institute of Technology have also entered the global top 20, indicating that the current international competitiveness of AI in Chinese universities cannot be underestimated. At the same time, domestic companies have also put efforts into AI talent training. In October 2021, the founder, chairman, and CEO of Baidu, Robin Li, said at the Peking University New Engineering International Forum that "Baidu will train 5 million AI talents for society in the next 5 years."

Table 3.1 CSRankings' top 20 universities in mainland China in the AI field, 2020-2021

Ranking	Name of School	Score	No. of faculty in field	Ranking	Name of School	Score	No. of faculty in field
1	Tsinghua University	18.5	68	11	University of Electronic Science and Technology of China	5.7	36
2	Peking University	17.9	90	12	Beijing University of Aeronautics and Astronautics (Beihang University)	5.4	27
3	Chinese Academy of Sciences (CAS)	13.5	47	13	Sun Yat-sen University	4.8	11
4	Shanghai Jiao Tong University	11.1	42	14	University of Science and Technology of China	4.8	18
5	Zhejiang University	10.1	55	15	Soochow University	3.1	23
6	Nanjing University	8.7	42	16	ShanghaiTech University	2.8	11
7	Harbin Institute of Technology	7.6	48	17	Xi'an Jiaotong University	2.7	17
8	Renmin University of China	7.0	27	18	Northwestern Polytechnical University	2.5	11
9	Fudan University	6.7	30	19	Shandong University	2.4	8
10	Beijing University of Posts and Telecommunications	6.0	42	20	Westlake University	2.3	3

Data Source: CSRankings (Note: Ranking scores are calculated based on the geometric mean of the number of papers published by each institution at top academic conferences in the AI field.)

Although China has achieved remarkable results in AI talent pool building, a considerable gap remains compared with AI powerhouses such as the United States. In terms of talent training structure, the United States is far ahead in AI doctoral training. According to statistics, 44% of AI talents received their doctoral degrees in the United States, and only 11% received their doctoral degrees in China, followed by the United Kingdom (6%), Germany (5%), and Canada, France, and Japan (all 4%). This shows that the international attractiveness of AI education in China still needs to be strengthened (Figure 3.1). As for the distribution of talent by source, China's current AI talent pool consists mostly of local talent, which accounts for 90.81%, while overseas talent accounts for only 9.19%, reflecting the need to further increase the internationalization level of China's AI talent pool (Figure 3.2).

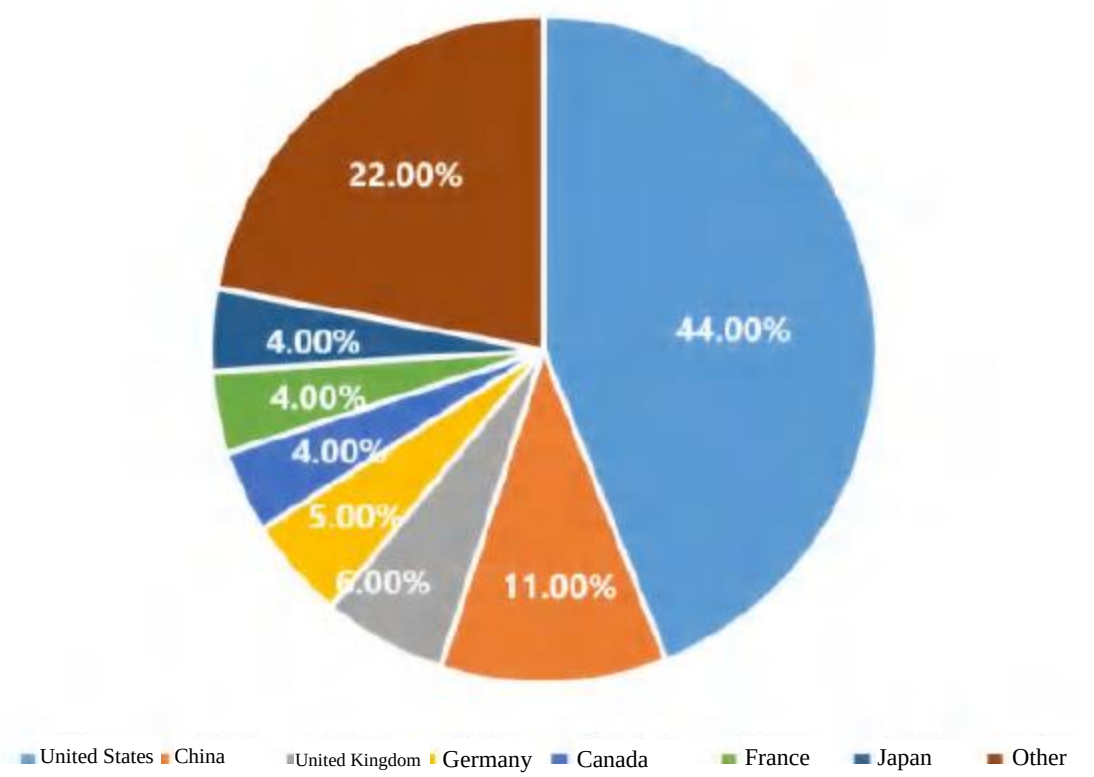


Figure 3.1 Statistics on percentages of AI PhDs earned in major countries

Data source: Market analysis of China's AI industry in 2019: The talent gap exceeds 5 million; three aspects of making up the shortfall in the future. [EB/OL]. https://www.sohu.eom/a/326990725_473133,2019-07-15.

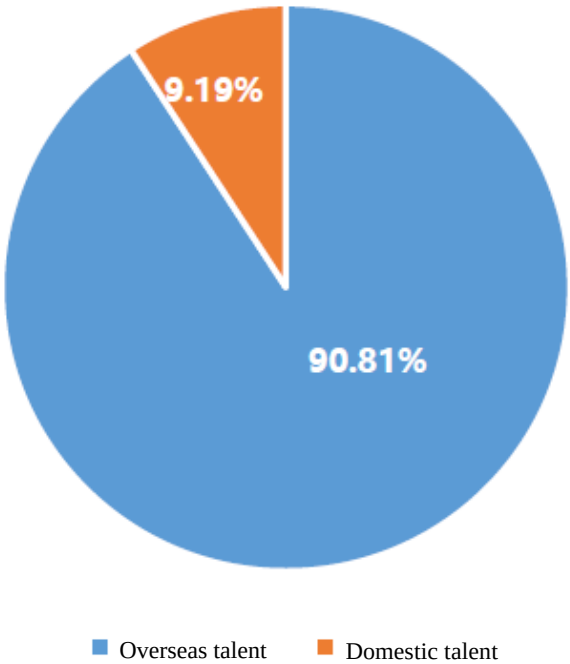


Figure 3.2 Overseas AI talent percentage

Data source: *2019 China AI & Big Data Talent Employment Trend Report*

In terms of the distribution of AI talent by field, the *2017 Global AI Talent White Paper* showed that China lagged behind the United States in the supply of AI talent in four major fields: processors and chips, machine learning applications, natural language processing, and intelligent drones. The largest gap was in processors and chips: Statistics showed that the United States had 17,900 practitioners in this field, while China had 1,300, less than 10% of the United States. Next is natural language processing, where the United States had 20,200 people and China had 6,600 people. Finally, in the computer vision and robotics learning fields, the numbers of practitioners in the United States were 2.9 times and 1.8 times those of China, respectively. China only exceeded the United States in the field of intelligent robotics.

2. Current AI talent demand

China's demand for AI talent continues to expand along with the AI industry's rapid growth. The *2019 China AI & Big Data Talent Employment Trend Report* released by liepin.com (猎聘网) compares and studies the changing trends of talent demand in the national AI and big data field and the internet industry, and finds that, as of the second quarter of 2019, the demand for talent in the AI and big data field had increased by more than 11 times compared to the first quarter of 2015, and the multiple was significantly higher than that in the internet industry. The contradiction between fast-growing AI talent demand and lagging talent supply continues to grow. A report issued by the Ministry of Human Resources and Social Security (*Analytical Report on Current Employment Prospects for Artificial Intelligence Engineers and Technicians*) notes that the current shortage of AI talents in China is more than 5 million, and with the domestic supply-demand ratio being 1:10, there is a serious imbalance between supply and demand.

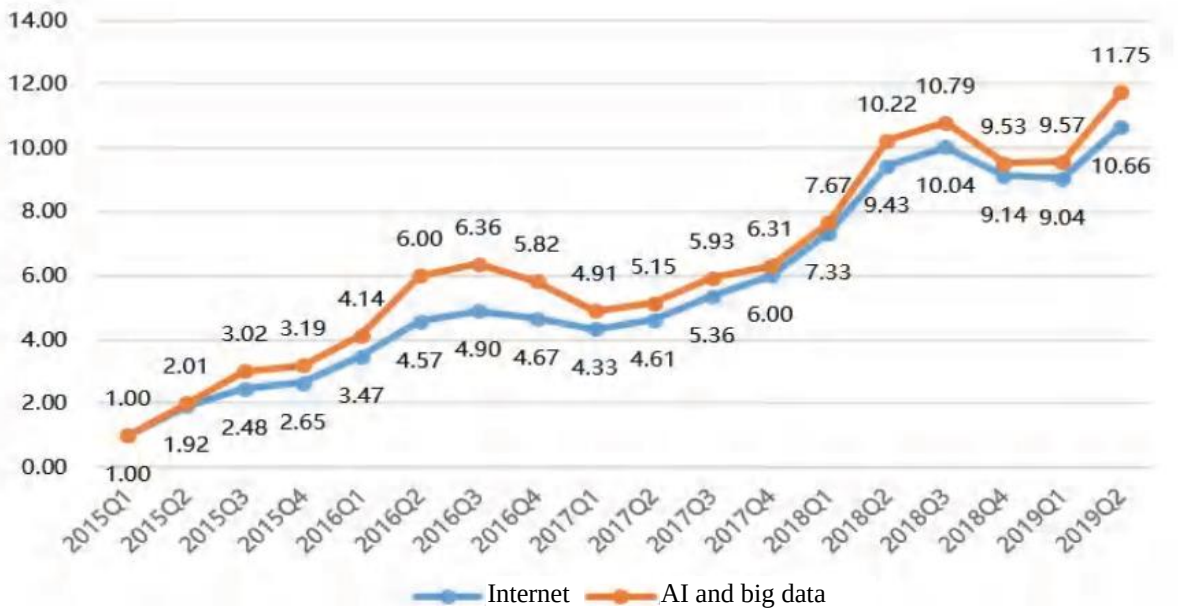


Figure 3.3 2015Q1-2019Q2 national talent demand trends in the AI & big data field and the internet industry

Data source: liepin.com "2019 China AI & Big Data Talent Employment Trend Report"

In terms of job types, the talent supply-demand ratio for technical positions is much lower than that for practical skills positions. Technical positions include algorithm research, application

development, functional skill-based, and high-end technical positions, and with talent supply-demand ratios of 0.13, 0.17, 0.98 and 0.45 respectively, the talent gap is obvious. Practical skills positions include product manager, sales, and senior management positions, for which the talent supply-demand ratios are 4.52, 7.14, and 3.44 respectively, so the supply of talent is relatively sufficient. In terms of specific technical directions, the talent gap is relatively great for basic technology: The talent supply-demand ratios for AI chips, machine learning, natural language processing, and computer vision positions are less than 0.4, indicating that talent supply is seriously inadequate for these technology directions. In the case of intelligent voice and computer vision in particular, for which the talent supply-demand ratios are only 0.08 and 0.09 respectively, there is an urgent need to accelerate talent training.

From a talent quality standpoint, the overall quality of AI talents in China is still low at present, making it difficult to meet job demand. The *2017 Global AI Talent White Paper* found that nearly 30% of AI job seekers fall far short on the indicators required by AI employers. The underlying reasons for this include insufficient education, lack of experience, lack of practical skills, etc. The low quality of talent has led to an imbalance between supply and demand for many positions, especially some core positions. For example, 45.1% of algorithm research jobs and 41.9% of application development jobs require candidates to have a master's degree or above, but it is still difficult to meet these requirements with China's existing reserves of highly educated AI talents, leading to vacancies in some core positions. Moreover, given that the time required to develop qualified AI talents, especially highly educated AI talents, is much greater than for general IT talents, gaps caused by talent quality issues may be hard to close effectively in the short term.

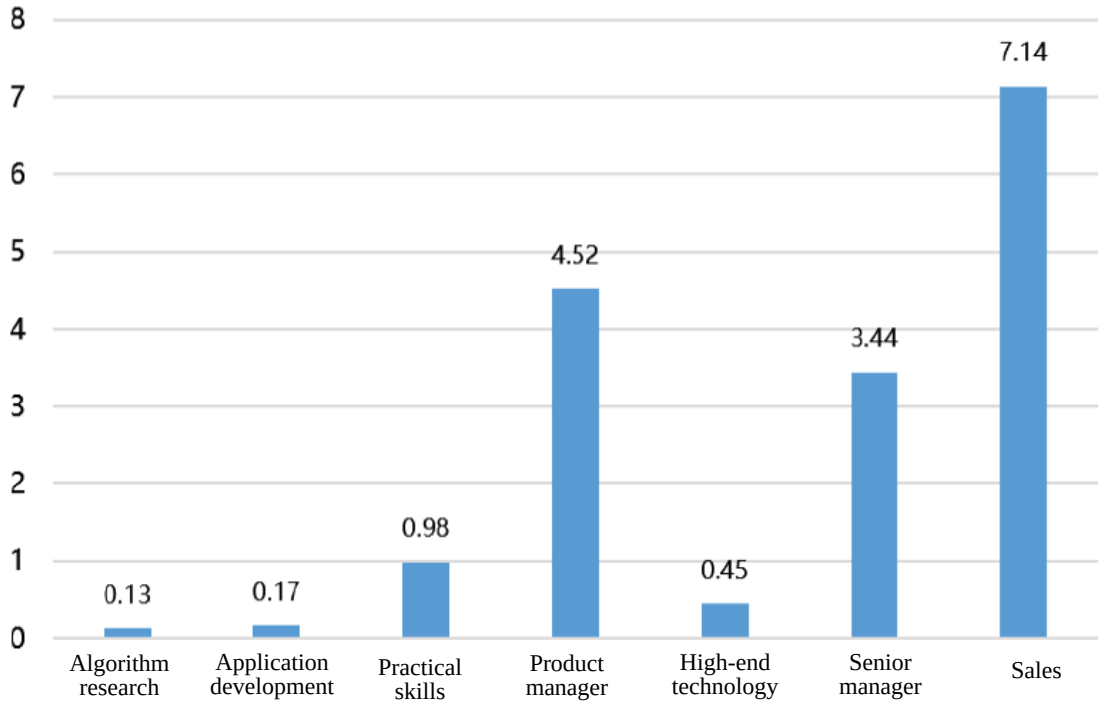


Figure 3.4 Supply-demand ratios of different functional positions

Data source: *Artificial Intelligence Industry Talent Development Report (2019–2020)*

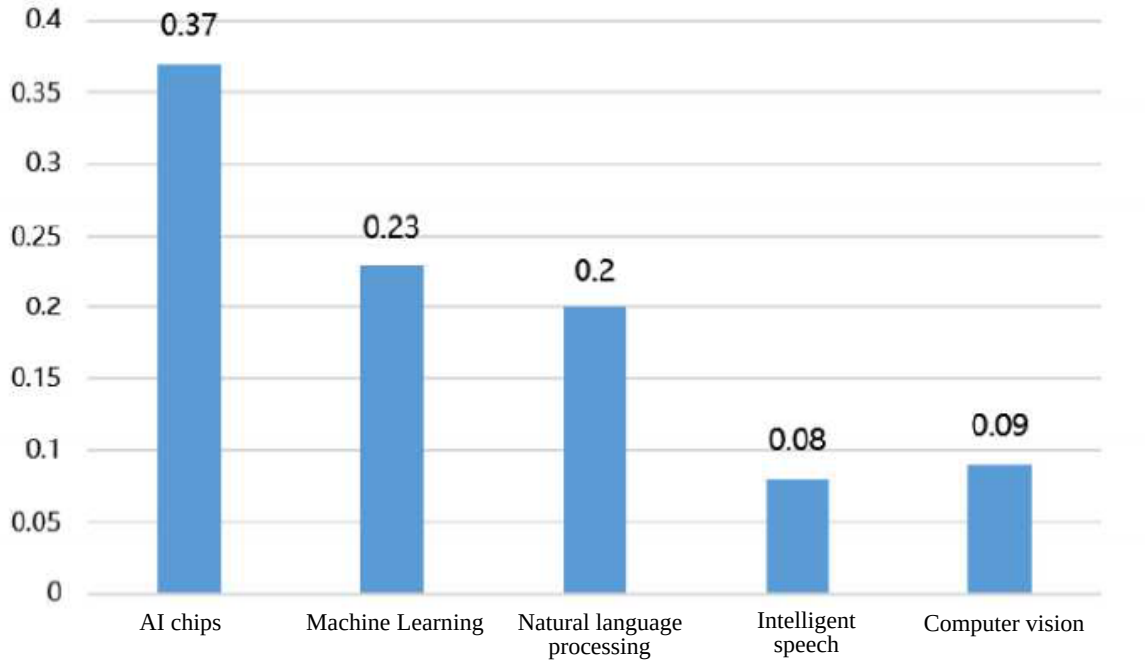


Figure 3.5 Supply-demand ratios of technology-oriented positions

Data source: *Artificial Intelligence Industry Talent Development Report (2019–2020)*

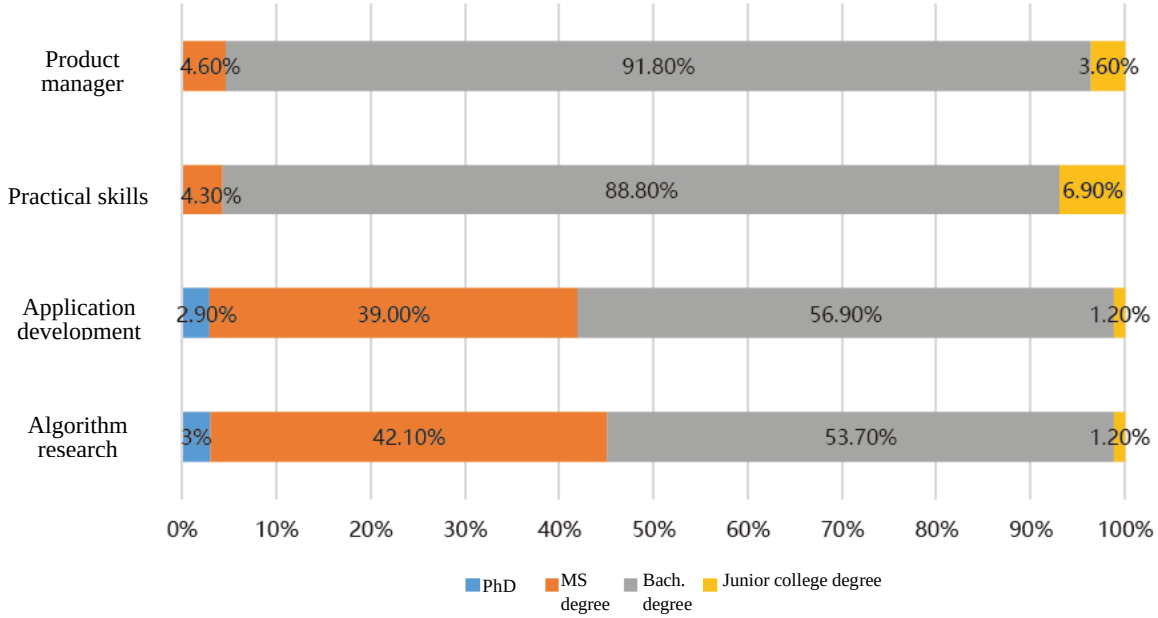


Figure 3.6 Academic requirements of the main AI positions

Data source: *Artificial Intelligence Industry Talent Development Report (2019–2020)*

3. Current Distribution of AI Talent

Domestic AI talent is currently characterized by a strong association with regions. On one hand, domestic AI talents are concentrated in leading technology companies—Baidu, Alibaba, Tencent, iFlytek, and others, and the emerging AI startups and unicorns in related fields also absorb

a large number of AI talents. On the other hand, AI companies and talents are concentrated in the Beijing-Tianjin-Hebei, Yangtze River Delta, and Guangdong, Hong Kong, and Macau regions, causing the distribution of AI talents to display a strong association with regions. According to data in *China's New Generation Artificial Intelligence Technology Industry Report 2020* released by the Chinese Institute of New Generation Artificial Intelligence Development Strategies (CINGAI), China's AI enterprises are distributed mainly in Beijing, Guangdong Province, Shanghai, and Zhejiang Province, which account for 42.5%, 16.9%, 15.3% and 8.3% of the total, respectively. Meanwhile, some 109 AI universities are distributed in 23 provincial-level administrative regions in China, but are most concentrated in Beijing, Jiangsu Province, Shanghai, Guangdong Province, and Zhejiang Province.[9]

B. University AI Talent Training Models and Characteristics

For the foreseeable future, prospective demand in China's AI market will be vast, so to support and promote the AI industry's development, high-quality and high-level talents are needed, especially talents who better understand creativity, cross-border aspects, and openness, and are better at cooperation and sharing, as well as hybrid talents (复合型人才) who combine theory and practice based on the intelligentization needs of industry. Toward this end, universities are taking advantage of opportunities to develop new science and engineering disciplines, establish AI major programs, lay out AI academic disciplines, and scale up their AI talent training.

1. Background of AI talent training in universities

There is a very profound real-world background to the efforts universities are making to develop AI talents: On one hand, enterprises are demanding higher and higher AI talent quality, with multidimensional, multilevel, and hybrid AI talents being particularly favored by enterprises. This poses a major challenge to the traditional talent training model based on knowledge of the discipline and using course-based learning as the primary approach. As the main force for talent training, universities must conform to the trends of the times, take advantage of the important opportunities that AI affords, and constantly update their talent training model, so as to achieve leapfrog development in talent training quality.

Column 3.1 AI talent quality expectations of enterprises

Although there are still a lot of jobs for students coming to Baidu specialized in big data, computing power, and deep learning algorithms, the requirements for students are now more challenging, especially in terms of cross-disciplinarity: If a product needs to be developed based on the interweaving of different disciplines, then we especially need students to have not only professional knowledge, but also a passion for AI technology and science, and a willingness to learn actively and work from diverse perspectives.

—Baidu Product Manager

On the other hand, AI technology is unique. AI is a general purpose and basic technology tool that concerns all aspects of future social development. It can even achieve disruptive innovation in some areas, and become a powerful tool for innovation and development in multiple industries. Therefore, to enable the development and transformation of different industries, future AI talents will not only need to be proficient in AI field knowledge and skills, but will also need to be familiar with specific applications of these technologies.

Finally, universities are still the key actors for promoting cutting-edge technological breakthroughs in AI, and they shoulder the important task of developing high-level AI talents. Undoubtedly, universities are where the primary productive force (S&T), the primary resource (talent) and the main driving force (innovation) come together. Holding enormous scientific research and innovation resources, and gathering the highest-quality AI scientific research forces in China, universities represent the cutting-edge direction of AI technology development. At the same time, they bear the key responsibility of developing AI talents, and have an inescapable mission when it comes to our strategic reserves of AI talents.

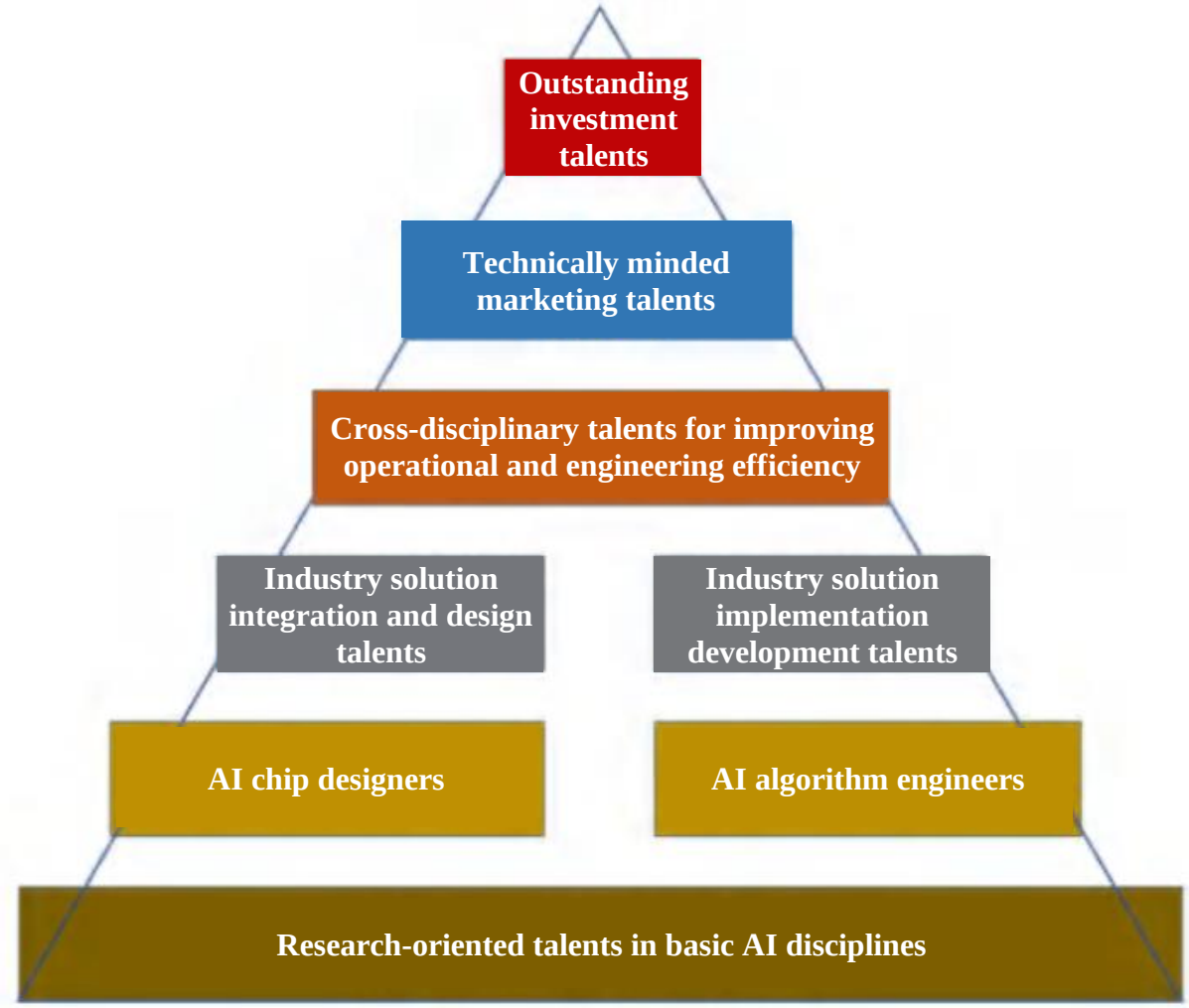


Figure 3.7 Multidimensional, multilevel, and hybrid talents

2. AI talent training directions in universities

At present, relatively few universities have established separate AI major programs, most having established a number of training directions under computer technology application majors, including directions in three categories: (1) General synthesis. Students' quality in terms of basic AI theory is cultivated with the goal of developing a general foundation in AI disciplines such as intelligent science and technology, AI, computer software, and theory. (2) Professional applications. Students' application skills are cultivated with the goal of promoting the specific

application of AI technologies, such as machine learning, natural language processing, intelligent vehicles, smart manufacturing, computer vision and imaging, intelligent robotics, pattern recognition, and intelligent systems. (3) Cross-fertilization. Students' knowledge cross-fertilization and innovation awareness are cultivated based on the need to promote the synergistic development of AI and other disciplines, such as AI and medicine, intelligent transportation, business intelligence, smart design, etc.[10]

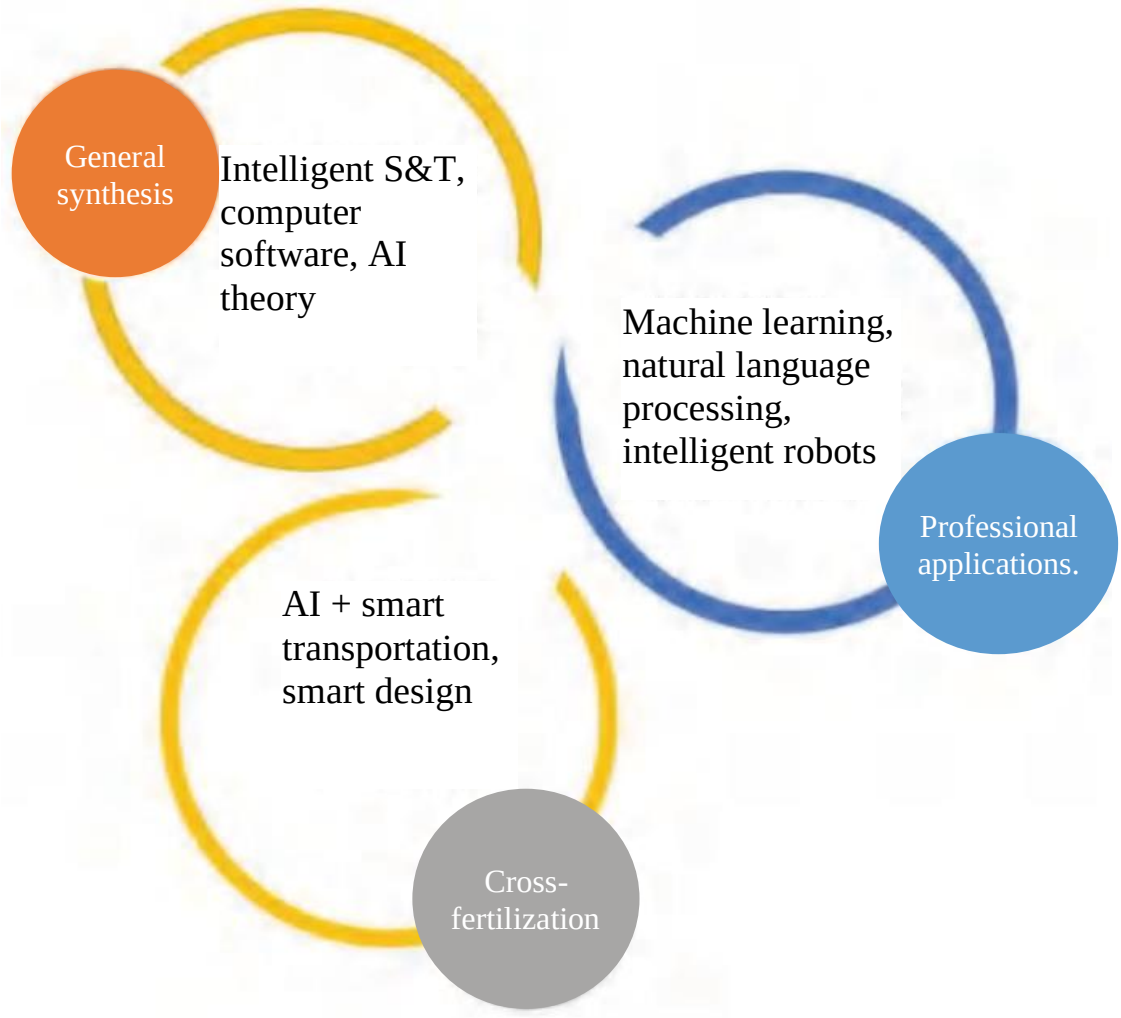


Figure 3.8 AI talent training directions

3. Construction of AI curricula and majors by universities

There are three main models of AI curriculum construction by universities: new AI majors, new AI training directions in existing related major programs, and reorganization of existing related major programs to establish AI institutes.

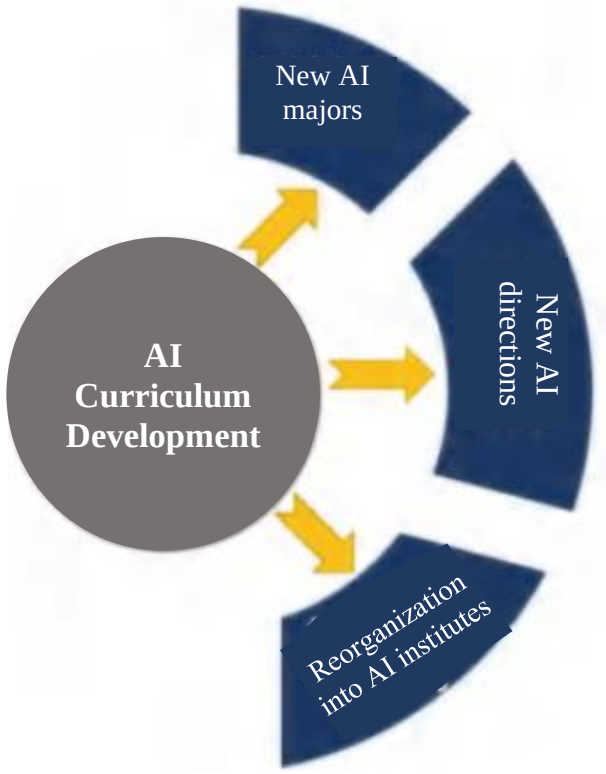


Figure 3.9 Main AI curriculum-building methods of universities

The building of AI curricula and majors by universities has the following features:

(1) AI talent training goals focus on basic theory and method innovation. At universities, especially first-class universities,[2] AI talent training starts from a high level, and the training goals are aimed more at basic and original theoretical innovation in AI, focusing on major cutting-edge scientific problems in AI fields. They are committed to developing high-quality AI talents who are "high-level, hybrid, and international" to lead the cutting-edge development of China's AI industry.

(2) Widespread adoption of talent training approaches that cross-link multiple related disciplines. At present, most universities have adopted "discipline-derived" construction of AI curricula and majors. That is, development of AI talents is based on the foundation of existing disciplines, taking full advantage of the superior resources of existing curricular platforms, such as computer science faculty and laboratory resources. They offer students a more general, comprehensive and integrated AI learning experience by further enhancing the deep cross-fertilization of multiple disciplines. For example, by establishing new "AI+X" hybrid major training models, which emphasize the cross-fertilization of AI with mathematics, medicine, biology, finance, and other disciplines, the hybrid character of AI talents is further enhanced.

(3) Most schools implement joint guidance models with AI field mentors from within and outside the institution. AI is not only a basic discipline but also a practical discipline with

[2] Translator's note: The Chinese government launched the "world-class universities and world-class curricula" (世界一流大学和一流学科) initiative, abbreviated "double world-class" or "double first-class" (“双一流”), in 2017 with the aim of increasing the number of Chinese universities that rank among the world's best.

significant practical application value, so AI curricular content is updated rapidly and needs to be closely linked to practice. For this reason, most universities adopt a combined tutors approach, in which on-campus tutors are responsible for leading students toward building a good foundation in AI theory, while off-campus tutors enhance their practical abilities in AI. At the same time, the quality of AI talent training and students' professional quality and abilities are improved through participation in research training and practical training.

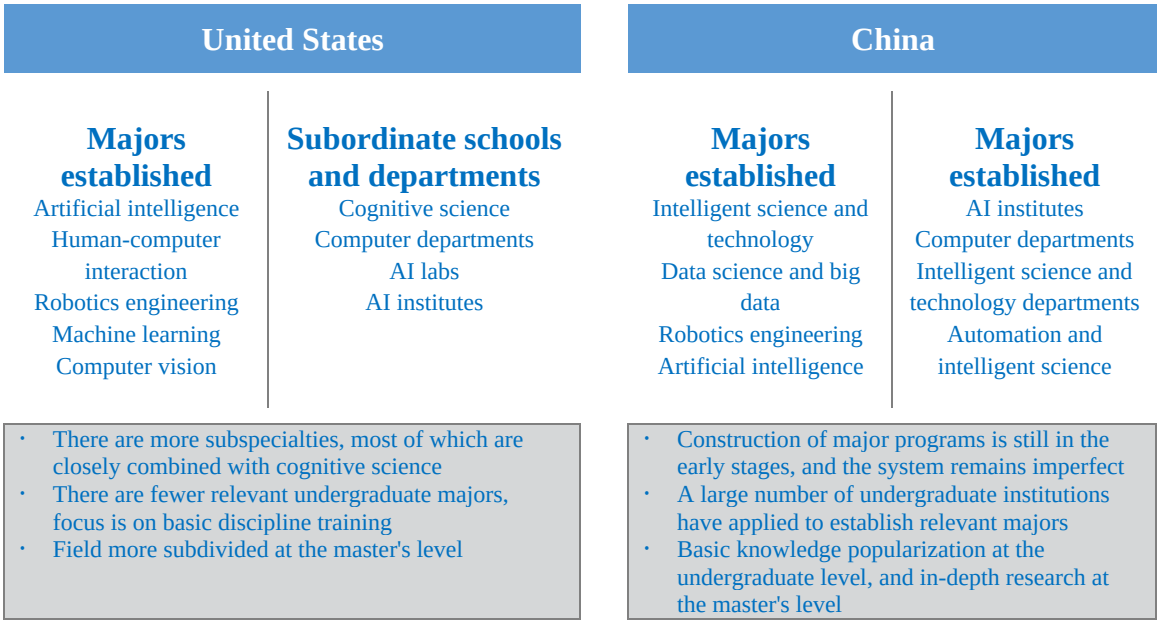


Figure 3.10 AI-related majors and subordinate schools in China and the United States

Data source: EO Intelligence *2020 Global AI Talent Training Research Report*

Table 3.2 Main goals of building AI curricula and majors by universities

Xi 'an Jiaotong University – College of Artificial Intelligence

♦ Undergraduate AI program aimed at cultivating excellent top-notch talents who have a solid grasp of basic theory, fundamental methods, and applied technology in AI, are familiar with interdisciplinary knowledge related to AI, and can play a leading role in developing China's AI science and technology industry in the future.

♦ Establish eight major course clusters (mathematics and statistics, science and engineering, AI core, computer science core, cognition and neuroscience, AI and society, advanced robotics, and AI platforms and tools), with each course cluster consisting of several compulsory courses and elective courses.

♦ Strengthen deep cross-fertilization of multiple disciplines, focusing on the major cutting-edge issues and bottlenecks in applied fundamental AI theory, and on research and applications for major national needs, and cultivate excellent talents for the future development of AI.

♦ Focus on carrying out systematic research on how to design more robust AI, hybrid augmented intelligence with human-machine collaboration, and core chips and new computing architectures for AI technologies.

Shanghai Jiao Tong University – Wu Wenjun Artificial Intelligence Doctoral Program

♦ Aiming at cutting-edge AI science and technology and major strategic needs, conduct original research, cultivate a group of leading talents in AI with broad vision, innovation ability, and social responsibility, and promote AI science and technology innovation.

♦ Implement the internal and external mentors joint mentoring model, in which excellent mentors from the university partner with top overseas scientists or AI industry leaders.

♦ Establish a new "AI + X" combined major training model, emphasizing the cross-fertilization of AI with mathematics, medicine, biology, finance, and other disciplines.

University of Chinese Academy of Sciences (UCAS) – School of Artificial Intelligence

♦ Uniting with internationally influential educational research institutions and leading enterprises in the field of intelligent S&T, and aiming at the talent training goal of "high-level, hybrid, and international," create a top domestic and internationally renowned base for the development of talents in the field of intelligent S&T.

♦ Focusing on the core science and key technologies in the field of AI, and addressing the international cutting edge of the discipline and development needs of society, the school will form an education and research system in which scientific research, education, and industry are deeply integrated, training of innovative talents and training of technical application talents are complementary, and professional training is combined with customized training.

♦ Oriented toward the international scientific frontier, the School of Artificial Intelligence has six teaching and research departments: pattern recognition, basic AI, brain cognition and intelligent medicine, intelligent human-computer interaction, intelligent robotics, and intelligent control.

University of Electronic Science and Technology of China – Artificial Intelligence Major

♦ Cultivate high-level talents who have solid AI theoretical knowledge and technical and engineering abilities, and are able to apply basic AI models, principles, and methods to design effective engineering solutions.

♦ Achieve multidisciplinary integration of computer science, automatic control, electronics, brain and cognitive science, etc.

♦ Use scientific research to promote teaching, use teaching to help scientific research, actively guide students to participate in scientific research, and improve students' innovation and practical abilities.

♦ Exercise students' ability to acquire knowledge, apply knowledge, and innovate, so that they can become hybrid talents who can engage in basic AI theoretical research, applied technology R&D, and AI application and innovation.

Data source: Compiled from data collected by the research team through public channels.

4. AI curriculum development and teaching design in universities

In February 2021, the official website of the Ministry of Education announced the *Results of Filing and Approval of Undergraduate Majors in Regular Higher Education Institutions in 2020*, in which AI majors at 130 universities were approved. Thus far, 345 universities in China have established undergraduate majors in AI, and they play an active exploratory role in curriculum development and instructional design. According to the *2020 China AI Talent Training Report*, the construction of China's AI curriculum system started relatively late, and the curriculum is mainly based on international curriculum systems, but it has also formed unique "AI+" characteristics.

Tsinghua University Computer Science Pilot Class	Peking University Intelligent Science and Technology Major	Shanghai Jiao Tong University Computer Science Major
· In the first two years, intensive training in the fundamentals of computer science is carried out. · In the last two years, specialized education is carried out in theory, security, systems, computational economics, computational biology, machine intelligence, network science, quantum information, etc.	· Required throughout the school: mathematics, mechanics, electromagnetics · Required for major: mathematical logic, fundamentals of AI · Core of the major: specific AI directions · Quality-oriented education: other courses related to the major	· Courses for major : mathematics, introduction to computer science, physics · Required for major: data architectures, computer systems, algorithm fundamentals · Elective within major: Fundamentals of AI · Practical courses within major: programming, physics, teaching practice

Figure 3.11 AI curricula of three universities

Take the curriculum of the Yangtze River Delta Research University Alliance as an example: Foundational courses are divided into AI and machine learning, programming architecture, and lectures on cutting-edge hotspots, which help learners better grasp the basic theoretical context, as well as the cutting-edge hotspots in the field. The module courses are currently divided into six categories: intelligent perception and cognition, intelligent systems, smart design, smart decision-

making, smart cities, and robotics, from which learners can choose based on their own foundation and research interests. The minimum credit requirement is four credits, which learners must choose from within at least two categories, and they must complete at least one course in each category. The algorithm practice courses emphasize practice, with each course being one credit, and focus on developing and cementing learners' practical training ability. They are offered by Huawei, Baidu, Alibaba, SenseTime, Intel, and other famous enterprises, in cooperation with university teachers, to help learners understand and master the practice and application of AI in industrial scenarios. The cross-disciplinary electives cover multiple disciplines in order to break down the barriers between them, build a cross-disciplinary system, and help learners clarify the inherent logical relationships between different disciplines, grasp the intersection, integration, and interpenetration of theories in different disciplines, and enhance their scientific vision. Learners can choose relevant courses according to their own interests and energy.

Table 3.3 AI curriculum of the Yangtze River Delta Research University Alliance

Course type	Course name	Credits	Course taught by
Foundational courses			
AI and robotics	Artificial Intelligence: Models and Algorithms	2	Zhejiang University
Learning	Pattern Recognition and Machine Learning	2	Fudan University
Programming framework	AI Programming Framework	2	Zhejiang University
Lecture on cutting-edge hot topics	Lecture Series on the Brain and Cognition, and the Frontier and Application of Artificial Intelligence	2	Joint school-enterprise faculty
Modular courses			
Intelligent perception and cognition	Natural Language Processing	2	Harbin Institute of Technology, Zhejiang University
	Computer Vision	2	Shanghai Jiao Tong University, Zhejiang University
	Introduction to Brain Science	2	Zhejiang University, University of Science and Technology of China
	Intelligent Voice and Language Interaction	2	Shanghai Jiao Tong University
	Digital Image Processing	2	Fudan University
	Virtual Reality	2	Fudan University
Intelligent systems	AI Chips and Systems	2	Institute of Computing Technology, Chinese Academy of Sciences (CAS Institute of Computing Technology), Zhejiang University, Shanghai Jiao Tong University
	AI Algorithms and Systems	2	Zhejiang University
	Autonomous Intelligent Unmanned Systems	2	Tongji University
Smart design	Introduction to Visualization	2	Zhejiang University
	Design Thinking and Innovative Design	2	Zhejiang University

	AI and Data Design	2	Tongji University
Smart decision-making	Reinforcement Learning	2	Nanjing University
	Game Theory	2	Peking University, Zhejiang University, Shanghai University of Finance and Economics
Smart cities	Cutting-Edge Smart City Planning	2	Tongji University
	IoT	2	Tongji University
Robots	Smart Robots	2	Tongji University
Cross-disciplinary elective courses			
Elective courses	Intelligent Medicine	1	Tongji University
	AI and Numbers	1	Shanghai Jiao Tong University
	AI and Pharmacology	1	Zhejiang University
	AI and Law	1	Zhejiang University
	Computational Social Science	1	Zhejiang University
	Intelligent Finance	1	Zhejiang University
	Intelligent Public Administration	1	Zhejiang University
	AI Ethics	1	Zhejiang University
	AI Ethics	1	University of Science and Technology of China

Data source: Annual Report on the Top-Notch AI Talent Training Project (2020)

The deep integration of new generation AI with education and industry continues to drive education and teaching process reorganization and model reengineering, and the personalized features of teaching design are becoming more and more significant. One is the formulation of personalized learning programs according to the AI learning needs of students at different levels and stages, so as to improve students' learning experience. The second is the use of technical means to help teachers improve teaching quality and achieve the unification of teachers' teaching with students' independent learning. The third is to focus on the situational teaching design of AI and promote profound changes in the teaching environment, emphasizing especially the design of teaching activities starting from real practical tasks, encouraging students to broaden their horizons and master their skills in the process of completing real design tasks.

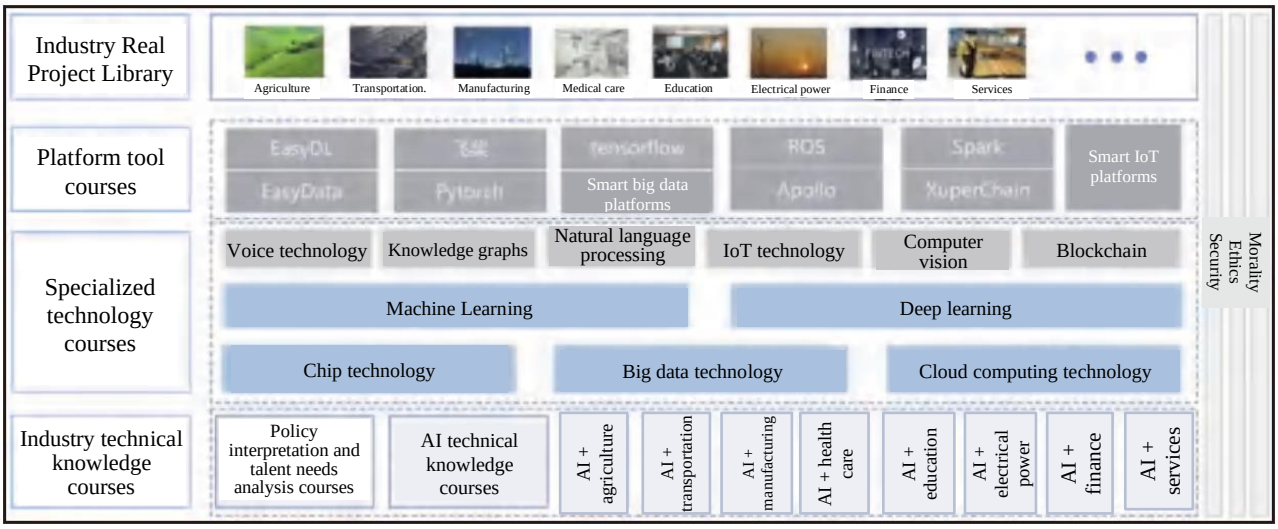


Figure 3.12 University-enterprise collaborative multi-category AI+ course system (taking Baidu as an example)

C. Enterprise AI Talent Training Models and Characteristics

Universities are the main actors in AI talent training, but they are not the only actors. The 2019 Government Work Report of the State Council pointed out the need to deepen the R&D and application of big data and AI, and improve integrated industry-academia-research institute innovation mechanisms with enterprises as the mainstay. As to AI technology companies that have been working on AI technology for a long time, the data, compute, and other teaching resources that universities lack are precisely the ones that such companies excel at. *China's New Generation Artificial Intelligence Technology Industry Report 2020* released by CINGAI shows that China ranks number-two in the world in the number of AI companies, second only to the United States,[9] and a large number of high-level AI leaders have emerged to play a key role in AI talent training. For example, Baidu plans to train five million AI talents for society within five years.

Table 3.4 University-enterprise cooperation in AI school construction

Name of enterprise	Cooperative or jointly built AI schools (partial list)
Baidu	Gaoling School of Artificial Intelligence, Renmin University; School of Artificial Intelligence, Jilin University; School of Artificial Intelligence, Tianjin University; School of Artificial Intelligence, Dalian University of Technology; School of Artificial Intelligence, Beijing University of Posts and Telecommunications; School of Artificial Intelligence, Xidian University
Tencent	College of Artificial Intelligence, Shenzhen University and Tencent Cloud; Liaoning Technical University Tencent Cloud School of Artificial Intelligence; School of Artificial Intelligence, Shandong University of Science and Technology and Tencent Cloud; Liaocheng University (Tencent Cloud) College of Artificial Intelligence
MEGVII	School of Artificial Intelligence, Nanjing University; College of Artificial Intelligence, Xi'an Jiaotong University

DeepBlue Technology	Central South University-DeepBlue AI Joint Research Institute; Jiangsu University of Technology, DeepBlue School of Artificial Intelligence
iFlytek	Nanning University iFlytek School of Artificial Intelligence; Anhui Institute of Information Technology, School of Big Data and Artificial Intelligence; Jiangxi College of Application Science and Technology, School of Artificial Intelligence; Chongqing Scientific Entrepreneur Vocational College, School of Artificial Intelligence

Data source: Compiled from data collected by the research team through public channels.

1. Data and platform-driven AI talent training

The development and optimization of underlying and general AI application technologies, including AI chips, deep learning frameworks, machine learning modules, and convolutional neural networks, as well as image recognition, speech recognition, and natural language understanding, are all highly dependent on training with vast quantities of data, and high-level AI talent training is also dependent on the support of vast quantities of high-quality data. The *2020 Tencent Artificial Intelligence White Paper* shows that vast data resources have already been formed in China by a large number of internet platform applications, including those of Tencent, Alibaba, Baidu, and others. Various industries and governments at all levels are also continuously enhancing their digital transformation and upgrading efforts, and with more extensive and diversified data resources being produced, data is becoming a national factor of production (生产要素).[11] With rich data resources, enterprises are actively participating in the AI talent training process by carrying out deep learning teacher training, publishing AI teaching materials, and providing supporting data, compute, courseware, experiments, competitions, and other AI teaching resources.

Column 3.2 PaddlePaddle industry-level open-source deep learning platform

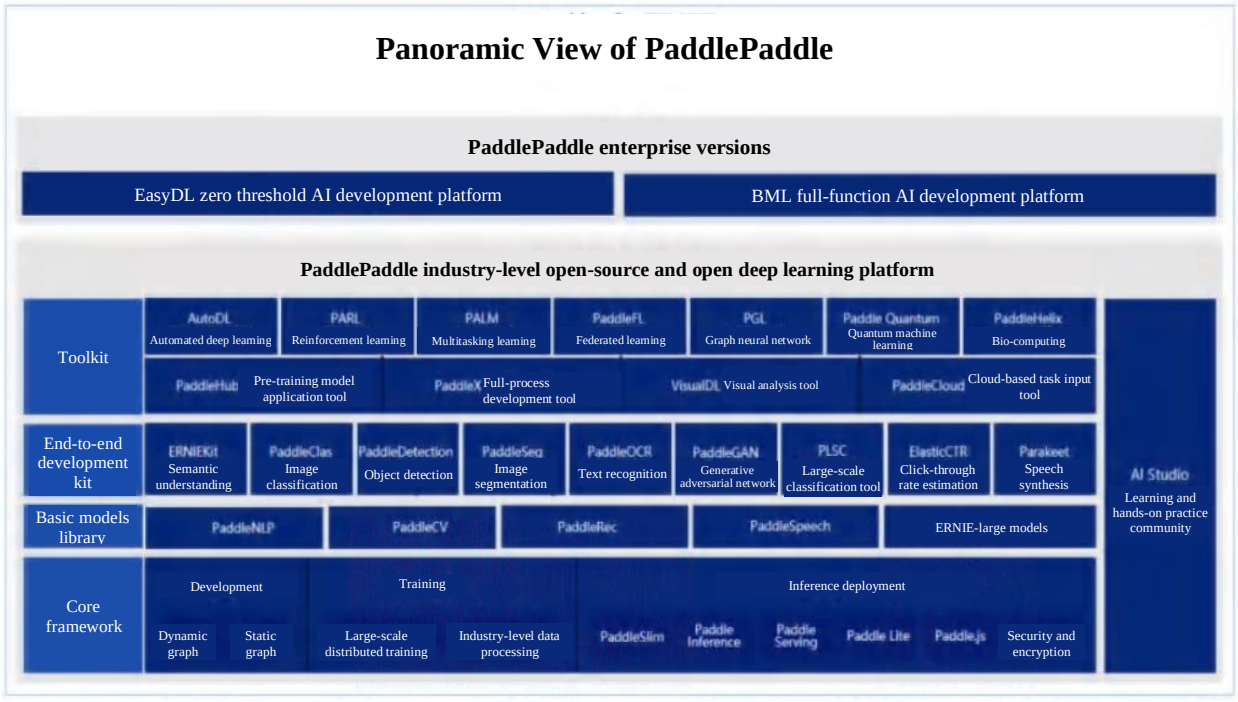
PaddlePaddle, based on Baidu's many years of deep learning technology research and business applications, is China's first self-developed, feature-rich, industry-level, open-source deep learning platform that integrates deep learning core training and inference frameworks, basic model libraries, end-to-end development kits, and a rich array of tool components. A report on deep learning framework market share for the first half of 2021, released by authoritative data research firm International Data Corporation (IDC), shows that Baidu's overall share of the deep learning platform market in China continues to grow, jumping to the number-one position.

In recent years, the Baidu PaddlePaddle industry-level open-source deep learning platform has seen several new feature releases and technical upgrades. These releases and upgrades include improving the performance and ease of use of the core framework, adding new industry-level model libraries (including the “ERNIE” large models, etc.), releasing the Paddle Lite end-to-side inference engine, releasing end-to-end development kits for industrial application scenarios (ERNIE semantic understanding for the natural language processing field, Paddle Detection object detection and Paddle Seg image segmentation in the computer vision field), etc. With the PaddlePaddle platform's further improvements in deep learning model development capability, training capability, and prediction and deployment capability following its function releases and technology upgrades, it is comparable to mainstream international frameworks such as

TensorFlow and PyTorch, and has better performance than the latter in many technologies. This development means China's AI technology developers and users do not have to rely on foreign platforms, and it can further foster an independent and controlled AI development and application ecosystem.

Baidu's PaddlePaddle has brought together 4.06 million developers. They serve more than 157,000 companies in dozens of industries such as finance, transportation, and logistics, and have created over 476,000 models based on the PaddlePaddle platform. PaddlePaddle assists developers in quickly implementing AI ideas and efficiently launching AI business, and is helping more and more industries realize AI empowerment and achieve industrial intelligentization upgrading.

PaddlePaddle AI Studio is a learning and training community based on Baidu's open-source deep learning platform. It integrates open data, open-source algorithms, and free compute to provide developers an efficient and easy-to-use learning and training environment, high-quality practical training cases and advanced courses, and various high-value competitions with large prizes, creating a full-cycle "learning-practice-competition-certification-employment" service system for developer growth. PaddlePaddle AI Studio has become a gathering place for AI developers to learn, communicate, compete, and grow. In the past three years, with a powerful online programming environment, cloud-based graphics processing unit (GPU) supercomputing power and storage resources, a diverse abundance of training programs, and a flourishing and open community ecosystem, PaddlePaddle AI Studio has attracted more than 1 million regular users, while amassing 2.4 million+ practical training programs, 6,000+ classroom courses, 110+ competitions, and 80,000+ datasets. In 2020, PaddlePaddle AI Studio was selected as one of the 20 teaching platforms recommended to universities during the pandemic by the expert group of the Ministry of Education's university-academia cooperative education program, and it was named an "Excellent Software Education Platform of 2020."



2. Competition-based practical training in AI

Domestic mainstream intelligent enterprises (智能企业) have developed various types of AI competitions, innovated competition topics and formats, created open and comprehensive technical competition platforms, and attracted school students to participate in the competitions. This has improved the practical skills of AI talents, and also uncovered a large reserve army of outstanding AI talents. For example, Baidu Astar (百度之星) is the only enterprise-level programming event that has been held continuously in China for 17 years, with a total of over 300,000 participants representing more than 1,000 universities. Astar, together with the four other major programming competitions (NOI, ACM, GCJ and Hack up), form the Grand Slam of the programming world, building Baidu's technical leadership status and the influence of its technical brand lineup, and promoting the growth of talents in China's internet and AI fields. In addition, competitions also include the China University Computer Competition - Artificial Intelligence Creativity Competition (C4-AI), the National University Student Intelligent Vehicle Competition, the Belt and Road Initiative (BRI)[3] International Big Data Competition, etc.

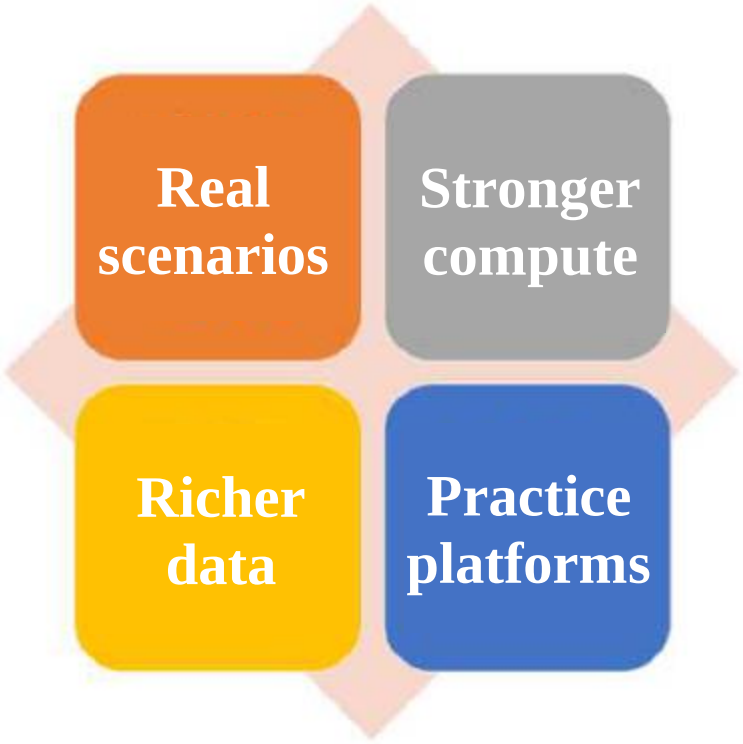


Figure 3.13 Advantages of enterprises participating in AI talent training

[3] Translator's note: The “Belt and Road Initiative” (“一带一路”), abbreviated BRI, refers to the Silk Road Economic Belt (丝绸之路经济带) and the 21st Century Maritime Silk Road (21 世纪海上丝绸之路).

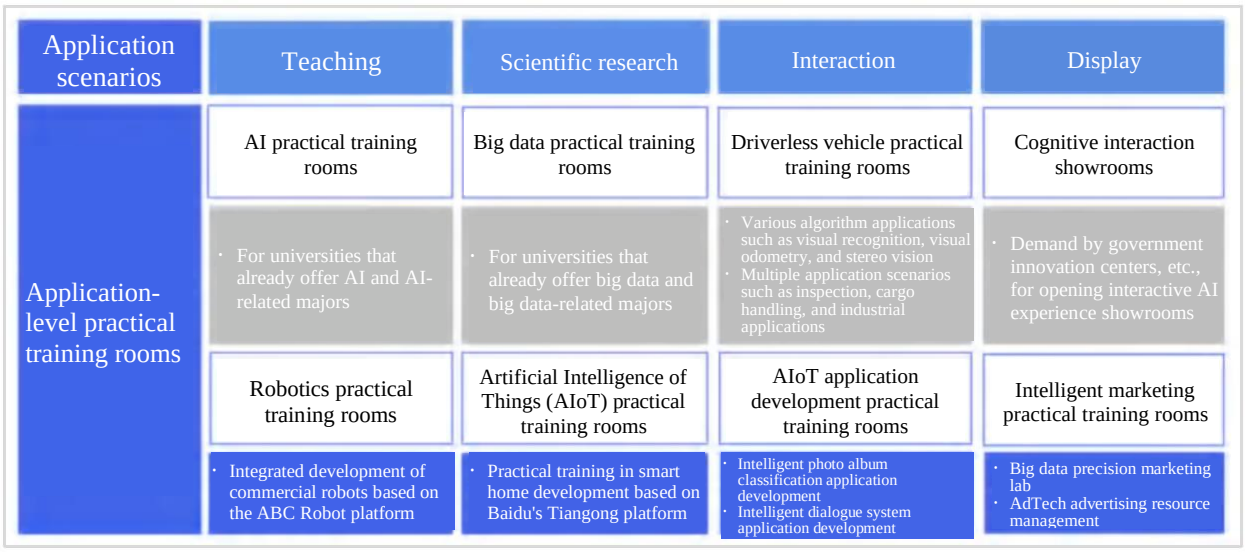


Figure 3.14 Enterprise AI training spaces based on application scenarios

3. Conducting bootcamps to reinforce practical experience

Influenced by AI bootcamps and online AI courses in foreign countries, especially the United States, large domestic AI technology-based enterprises are also relying on enterprise test platforms, enterprise data resources, and AI talent resources for students and newcomers to the AI workplace to carry out short-term training. The teacher team, which mainly includes technical leaders and well-known scholars from giant technology companies, can teach a large number of enterprise AI application cases in a short period of time, thereby improving trainees' practical skills.

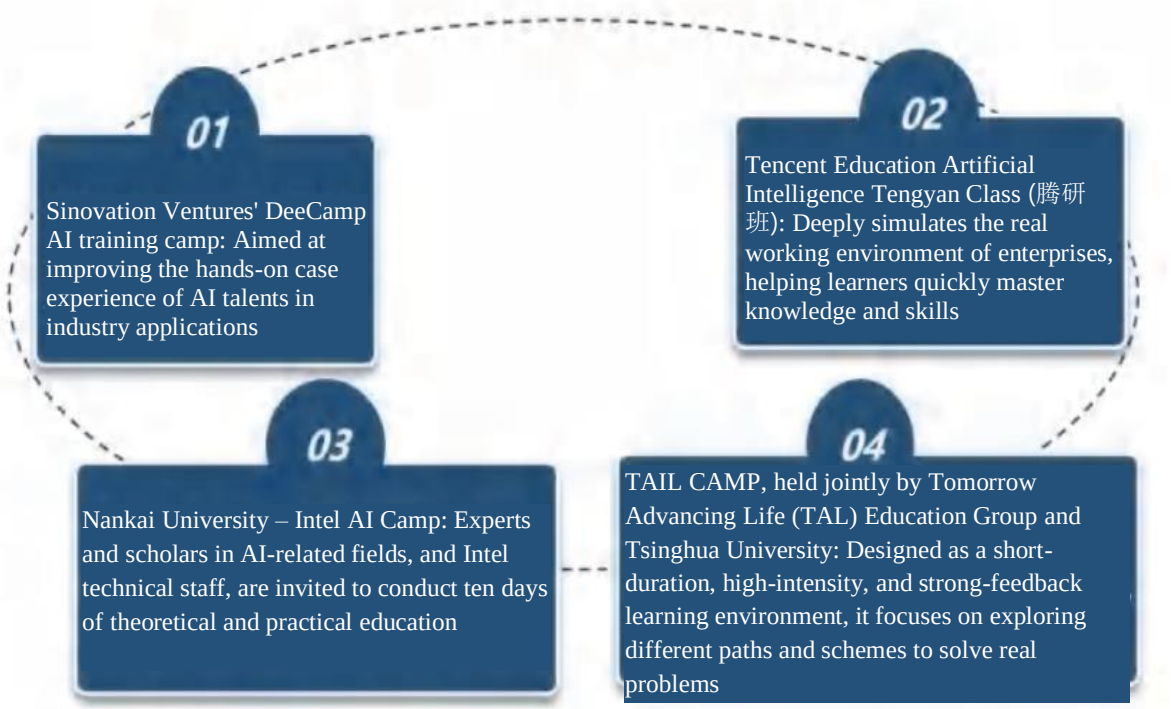


Figure 3.15 AI bootcamps

Data source: EO Intelligence

In addition, some enterprises have organized multiple types of student clubs and AI-themed youth academic forums, at multiple levels and closely related to AI talent cultivation. Drawing on community-run approaches, they regularly share AI content and communicate online, and attract top AI students around the world to participate, while enterprises provide data and open platform support for research work and participation in the research practice of their core technology projects. This accelerates the production of innovative knowledge, and has gradually become an important measure to speed up the domestic AI talent-building system and cultivate and build reserves of future technical leaders of AI in China.

Column 3.3 Xi 'an Jiaotong University—Baidu Big Data AI Elite Class

Aiming at elite education, the Baidu Big Data AI Elite Class (the "Elite Class") was jointly established by Baidu and Xi'an Jiaotong University to develop outstanding talents who have expertise in big data AI applications, love AI application technology, and have a mastery of certain big data AI application research methods and a sense of innovation, and have innovation ability, practical ability, and an international vision, thus delivering outstanding talents for the development of the nation's big data AI application undertakings. As of December 2021, the Elite Class had conducted six consecutive enrollment sessions, attracting more than 800 students to register, and enrolling a cumulative 265 students.

The Elite Class is a two-fold combination of cutting-edge theoretical learning and practical internship, with outstanding talents being jointly cultivated through school-enterprise cooperation. During the one-and-a-half-year study period, students can participate in different stages of learning, including theoretical courses, big data competitions, practical internships, and team building. Baidu has customized online courses for students in the AI Elite Class, so students can arrange their study time freely and achieve systematic learning of AI technology anytime, anywhere. In order to accelerate AI talent training, Baidu carries out comprehensive AI talent discovery through continuous school-enterprise cooperation. Empowered by Baidu's own leading technology platforms, professionals in the field, and other resources, the new model combining cutting-edge theoretical learning with practical internship is used to stimulate more students' interest in AI, adding strength to big data and AI project construction efforts.

4. School-enterprise collaborative participation in drafting AI talent standards

First, industry-leading enterprises are actively participating in the formulation of national standards. For example, the China Software Industry Association (CSIA) group standard, *Intelligent Terminal Deep Learning Inference Engine Application Programming Interface (API) Specifications*, compiled by Baidu as the lead unit, was released in December 2019. The development of this standard can meet the diversified application needs of developers and users while solving the problems of duplicated application development and inconsistent engine effects, reduce the cost to application developers of using deep learning technology, and promote the benign development of the inference engine ecosystems and the integrated use of resources.

Second, schools and enterprises are collaborating on improving AI knowledge system certification. Since October 2019, Baidu has cooperated with the Department of Higher Education of the Ministry of Education to issue the *Notice of the Department of Higher Education of the Ministry of Education on the Collection of Teaching Resources for Artificial Intelligence Majors* to collect digital teaching resources. The collection is targeted at the first 35 universities to have offered AI majors. On December 30, 2019, the construction of the first batch of emerging teaching resources for AI was basically completed, forming a *Basic Artificial Intelligence Course Knowledge System* approved by 35 schools. Totaling over 90,000 words, the system covers seven knowledge areas, 81 knowledge units, and 400 knowledge points of AI.

Third, enterprises are involved in the construction of AI talent competence assessment standards. For example, in 2018, Baidu joined hands with the National Engineering Laboratory for Deep Learning Technology and Applications and the CSIA [System and] Software Process Improvement Branch to jointly draft and release the first professional and technical talent training standard in the domestic AI field, the *Evaluation Standard for Deep Learning Engineers* (the *Standard*). The development of talent requires systematic talent education and certification

standards as guidance. The *Standard* was formulated with reference to the opinions and suggestions of many enterprises, professors from universities, and technical experts from enterprises in China's software industry, and the evaluation of deep learning engineers' abilities is divided into three levels: elementary, intermediate, and advanced. The elements of deep learning engineer ability assessment mainly include three major categories—professional knowledge, engineering ability, and business understanding and practice—and nine sub-categories. Drawing on the deep accumulation of Baidu and the National Engineering Laboratory for Deep Learning Technology and Applications in the AI technology and application fields, the *Standard* is a joint effort dedicated to training industry talents and promoting industry transformation.

5. Differentiated and precision (精准化) AI talent training

At present, the domestic school-enterprise cooperation model of AI talent training has begun to enter a refinement stage of systematic planning and precision linking, with the leading AI enterprises conducting precision training services for different trainees:

First is AI literacy training for CTOs. For the chief technology officers (CTOs) of small- and medium-size companies, mainstream AI companies have begun to actively explore the integration of innovative new trends in AI quality training, and in particular the achievement of an integrated role for compute, algorithms, and data in the AI field, as well as the close interaction and deep integration of AI technology in segments within the field, that is, promoting deep integration AI technology in realistic application scenarios to address industry-specific problems and application scenarios.

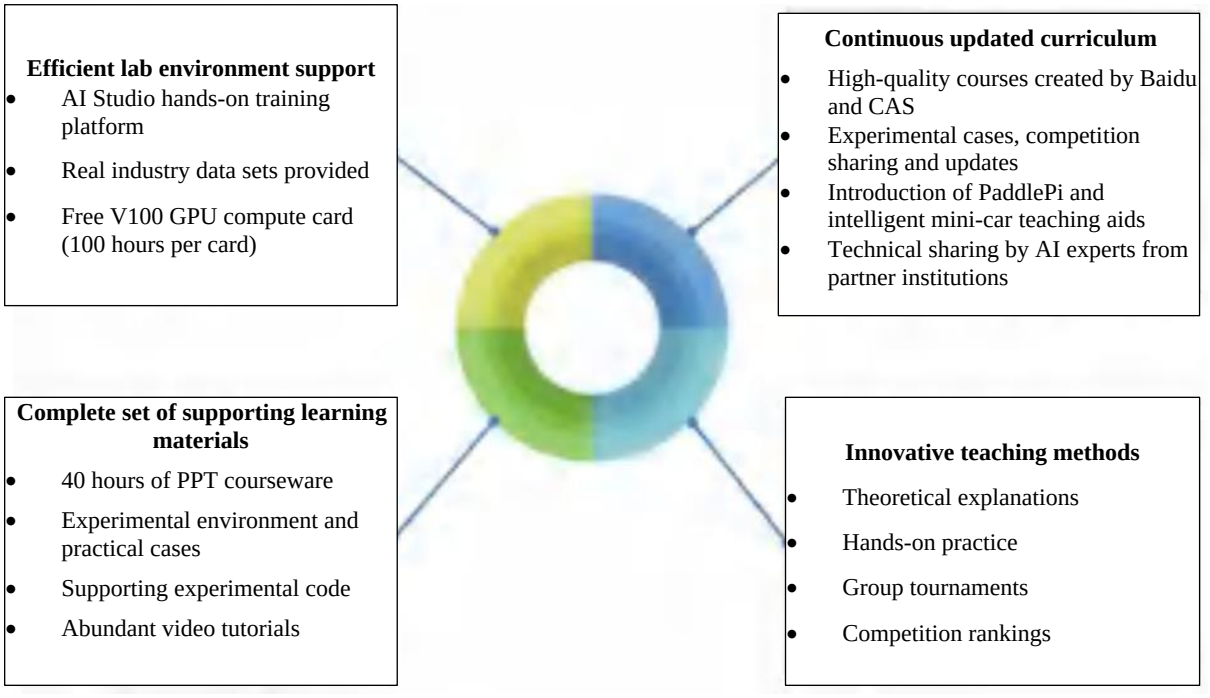
Second is AI capability training for university teachers. In order to promote AI talent training, under the guidance of the Information Technology Industry-Academia-Research Institute Alliance for New Engineering (新工科联盟) of the Ministry of Education, some top domestic AI enterprises have started to explore joint AI professional teacher training with universities. For example, since 2018, Baidu has been working with the Information Technology Industry-Academia-Research Institute Alliance for New Engineering, as well as with many key universities (Beihang University, University of Science and Technology of China, University of Chinese Academy of Sciences, Zhejiang University, Xi'an Jiaotong University, Central South University, Dalian University of Technology, University of Electronic Science and Technology of China, etc.), to hold a series of offline and online "Nationwide Deep Learning Faculty Training Courses for Universities." The course design combines theoretical fundamentals with intensive code practice, and provides supporting teaching materials, including professional textbooks, supporting courseware, practical platforms, open-source cases, and hardware teaching aids. Centered around PaddlePaddle's open-source and open industry-level deep learning platform, and based on PaddlePaddle's "AI Studio" learning and training community, it will improve the AI teaching and professional skills of university teachers, and promote cooperation and the exchange of teaching experience among teachers. By December 2021, a cumulative 26 training courses had trained over 3,000 professional teachers in universities, representing more than 700 universities in 31 provinces and cities across China. With 100% coverage of the 985 [Project] and 211 [Project][4] universities

[4] Translator's note: The 985 Project (985 工程), launched in May 1998, aims to transform China's top-tier higher education institutions into world-class universities so as to support China's modernization. The 211 Project (211 工程), launched in November 1995, aims to build a broader group of 100-plus universities—which includes the 985 Project schools as well as second-tier universities—into the core

nationwide, and a positive feedback rate of 99%, they have helped hundreds of teachers to successfully offer deep learning-related courses in their schools. Some of the typical cases that have been publicly reported are: Xu Yunfeng, a teacher at Hebei University of Science and Technology, started from scratch and used PaddlePaddle to build an on-campus AI experiment platform in just four months, solving a difficult practical problem for students; Sun Yu, a teacher at Beijing Forestry University, used PaddlePaddle to design an intelligent pest monitoring system for detecting red turpentine beetle infestations, which basically turned the monitoring and investigation of forestry pests and diseases from an outside-the-industry job to an inside-the-industry job. He instructed three students without AI backgrounds to design an intelligent inspection system using PaddlePaddle's EasyDL. The equipment has been put into operation, carrying out 6,000 inspections per day and saving enterprises nearly 2 million Chinese yuan Renminbi (RMB) annually.

Column 3.4 Improving training of deep learning teachers

Deep Learning Teacher Training is the first project of the Information Technology Industry-Academia-Research Institute Alliance for New Engineering targeting the development of deep learning teachers, and it is also one of Baidu's projects supporting the Ministry of Education's University-Industry Collaborative Education Program (产学合作协同育人项目). Since May 2018, Baidu has held 26 deep learning teacher training courses in many places in China, training more than 3,000 AI deep learning teachers for free and helping 700+ universities to offer deep learning courses.



source of talent for China's economic and scientific development in the 21st century.

Third is AI technology training for developers among the public (including students). On one hand, enterprises are sending enterprise-based teachers to universities through school-enterprise cooperation and collaborative education, relying on the national education reform strategy, based on their technical advantages and technical expert resources, and accommodating the requirements of schools. Such teachers offer special practice courses, provide high-quality practice and cutting-edge guidance, integrate industrial concepts, technologies, and resources into the training system, curriculum, and practical training, and incorporate enterprise education practices, thereby deepening assistance to universities in developing AI talents, and cultivating high-quality and innovative talents with an industrial applications perspective. For example, Baidu and the Shanghai Institute for Advanced Study of Zhejiang University signed a cooperation agreement on January 16, 2021 to focus on the developing trends and applications of AI centered around "computing + fields." Focusing on scientific and technological innovation, talent training, and other aspects of cooperation, they have partnered to promote a large cross-section of disciplines and a wide range of industry-education integration, to assist in the construction of Shanghai's "five centers" (“五个中心”) and to further build China's AI industry-academia-research institute innovation development ecosystem. On the other hand, enterprises are participating in AI talent certification, including examination certification, curriculum certification, professional certification, etc., to further link teaching and industry together, and continuously deliver high-quality talents to industry. For example, in 2020, Baidu's "AI Deep Learning Engineering Applications" certificate was selected for inclusion in the fourth batch of vocational skill level certificates. The certificate focuses on business design, engineering implementation, product testing, installation and deployment, system operation and maintenance, AI technical services, algorithm tuning, basic applications of deep learning frameworks, and other job skill requirements in "AI+" industry application scenarios. Designed for students of computer, electronic information, large electromechanical equipment, and other engineering majors, the certificates are issued as elementary, intermediate, or advanced in accordance with different training and assessment contents, with higher levels encompassing lower-level occupational skill requirements.

D. Problems and Shortcomings in AI Talent Training

1. Overall trend: insufficient total quantity and structural imbalance

In terms of the total amount of AI talent, the increase of talent in China's relevant fields is significant, but there is still a gap with the United States. At present, China's total AI talent is only about 50% of the total talent in the United States. Talent supply lags behind the United States especially in the four major areas of processors and chips, machine learning applications, natural language processing, and intelligent drones. In terms of top AI talent, Tsinghua University's "2020 AI Global 2000 Most Influential Scholars List" shows that among the top 100 scholars in each of 20 subfields (2,000 in total), the United States has an absolute advantage, accounting for 1,128 people, or 61.4%, while China has only 171 people, a mere one-seventh of the number in the United States. In terms of AI talent structure, China's basic layer reserves are relatively weak, and there is a shortage of leading talents. *China's New Generation AI Development Report 2019* shows that there is a certain degree of imbalance in the structure of China's AI talent. Specifically, the proportions of the numbers of basic layer, technical layer, and application layer talents are 3.3%, 33%, and 61.8%, in marked contrast to 22%, 37.3%, and 39.89% in the United States. In terms of AI talent quality, "large but not strong" is the crux of the problem in the construction of China's

AI basic R&D talent pool. A study conducted by Tsinghua University shows that for industry leader talents, in the United States, leading talents of AI enterprises with more than ten years in the industry accounted for 71.5%, while in China they only accounted for 38.7%, and a large number of leading talents are concentrated in the internet industry rather than in the AI industry per se. This exposes two major problems that still exist in the quality of AI talent training in China: First, a specialized structural system of AI talent training has not yet been formed in China's universities, the number of AI doctoral degrees awarded is low, and the AI talent pool in general is still plagued by problems such as low education level and lack of experience. The second is that the quality of fusion-type (融合型) talents with both professional ability and AI literacy in industrial applications needs to be improved, especially for core positions requiring high technical levels, such as algorithm research positions and application development positions.

2. University models: A disconnect between theory and practice

While universities in China are establishing one AI school after another, some problems and challenges in universities have been revealed in the practice of AI talent training: Most universities lack high-level AI curriculum development experience, lack massive high-quality data sets and computing resources, and have insufficient advanced practical teaching resources, professional cutting-edge faculty, suitable learning tools, practice and industry exchange opportunities, etc. These problems limit the ability of universities to educate people and cause a disconnect between theory and practice in AI talent training, further limiting China's ability to make rapid gains in the quality of AI talent training. The results of a follow-up survey by Baidu on the progress of 800 AI teachers in universities show that 65% of teachers think that AI technology updates and iterations are too fast, and it is difficult to do adequate course preparation in the rapidly changing technical environment; and 78% of teachers say that AI is a practical discipline with high data and computing power requirements, but the existing computer room resources of universities are not up to the task of large AI model training, hindering the development of high-quality AI talents. In addition, up to 83% of teachers believe that AI courses require not only knowledge teaching, but also various real project resources, which poses serious challenges when it comes to experiments, practical training, and other elements of teaching.

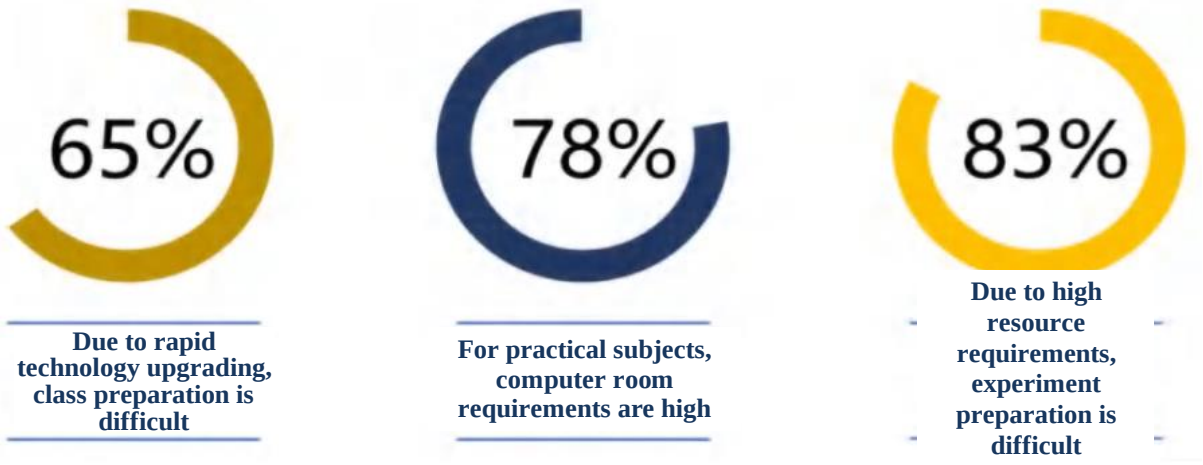


Figure 3.16 Problems in AI talent training at universities

Data source: Baidu data research

3. Enterprise models: A closed-loop ecosystem has yet to form

On one hand, the AI talent training of enterprises is not fully institutionalized and systematized, and the "simple fruit platter" (“简单拼盘”) phenomenon is common. The *2020 Tencent Artificial Intelligence White Paper* points out that, compared with universities, enterprises that directly face the market can more quickly reflect the changes in market demand for AI talents and quickly link feedback to the AI talent training and training process, so the enterprise-led AI talent training approach is characterized by rapid iterative updating of teaching methods, courses, and teaching materials. However, companies lack institutionalized and systematic AI talent training systems, and their reliance on short-term skills training and other teaching methods can easily cause excessive fragmentation of knowledge, which is not conducive to the systematically integrated and all-round cultivation of AI abilities.

On the other hand, the top domestic AI companies have not yet formed their own talent training ecosystem. Domestic AI companies generally use the existing international technical framework, making minor adjustments and breakthroughs within the framework, and emphasizing software update iterations, but neglecting development of the hardware foundation. In AI, for example, using GPUs and CUDA[5] from NVIDIA and other companies is still the most popular hardware-software combination, and although there are Chinese companies such as Cambricon that have made breakthrough attempts in niche areas, there are still significant gaps compared to the leading international companies, which leads to persistently high costs for enterprise-led AI talent training. In the AI algorithm area, foreign frameworks such as TensorFlow and PyTorch still dominate the mainstream, and talent training based on domestic deep learning frameworks represented by PaddlePaddle needs to be strengthened.

4. Core conclusion: The ecosystem for industry-education integration urgently needs to be improved

The industry-education integration model of AI talent training still needs sustained improvement. The current AI talent training model of industry-education integration is still limited to a few universities and AI industry giants, and the existing faculty strength, curriculum, and practical training system are hard-pressed to cover a wide enough range of application scenarios. As the integration of AI with other industries continues to accelerate, it is urgent for the industry-education integrated talent training model to widely absorb AI-related enterprises of various types and fields. This will provide more universities with practical experience, practical training courses, and frontline practical experts in multiple scenarios, thereby ensuring that the industrial talents developed by universities can be more widely adapted to the needs of multiple scenarios and industry requirements. In this regard, some foreign enterprises have formed a more ideal AI talent training system integrating industry and education. For example: Facebook has cooperated with New York University to establish a data science center devoted to jointly training AI talents; Google hires university talents to carry out basic research work in the enterprise on a permanent basis; and in France, research institutes, the university community, and relevant enterprises have jointly established "PRAIRIE" (Paris AI Research Institute).

The importance of constructing the AI talent ecosystem is increasingly pronounced. The core of AI competition is competition over high-level AI talents, and talent advantages will

[5] Translator’s note: CUDA is a parallel computing platform and application programming interface (API) developed by NVIDIA to allow software to use certain types of graphics processing units (GPUs) for general purpose computing.

determine the future of AI competition. According to a *People's Daily* report in July 2019, China has a population of nearly 1.4 billion, a labor force of 900 million, 170 million talents with higher education and specialized skills, and nearly 40 million university students, and these "demographic dividend" resources give China strong endogenous power in the competition for AI talents. In the face of increasingly fierce innovation-based competition, China urgently needs to establish an open and inclusive AI talent training ecosystem, take full advantage of the resources, capabilities, and strengths of various private entities, create an **integrated government-industry-academia-research institute model of AI talent training**, and maximize conversion of the demographic dividend in AI into a "high-quality talent dividend," so as to truly become the leader and innovator in the field of AI.

IV. Construction of an integrated government-industry-academia-research institute (政产学研) AI talent ecosystem

AI is a future-oriented technology development direction, and the core of global AI industry competition is AI talent competition. Raising the level of AI talents will help the global AI industry grow faster and stronger. However, the current global supply of AI talent is much smaller than the demand, and the AI talent gap is obvious. There is great demand for AI talents, be they research-oriented or application-oriented, and competition for talents among enterprises has gradually risen to become competition in industrial layouts and industry support at the national level. In the face of increasingly fierce S&T competition and industrial competition, China urgently needs to build a talent training system integrating government, industry, academia, and research institutes, in order to comprehensively improve the quality of AI talent in China.

A. AI Talent Competency Abilities and Categorization

1. Deconstructing the abilities of AI talents

Iterative technological updating has placed new demands on the overall quality and competency of AI talents. New generation AI talents need to have both professional knowledge and basic skills in the field of AI. They also need to have sufficient advanced skills in new generation AI fields such as AI applications, AI architecture, algorithm chip development, digital diverse collaboration, and AI ethics. Taking into account the relevant research data, this report proposes a future-oriented model of new generation AI talent competency. AI talent competency = basic skills + new generation AI skills, where basic skills include AI application skills, AI system architecture skills, fundamental AI professional knowledge, and AI expertise; new generation AI skills include algorithm chip development ability, digital diverse collaboration ability, and AI ethical responsibility.

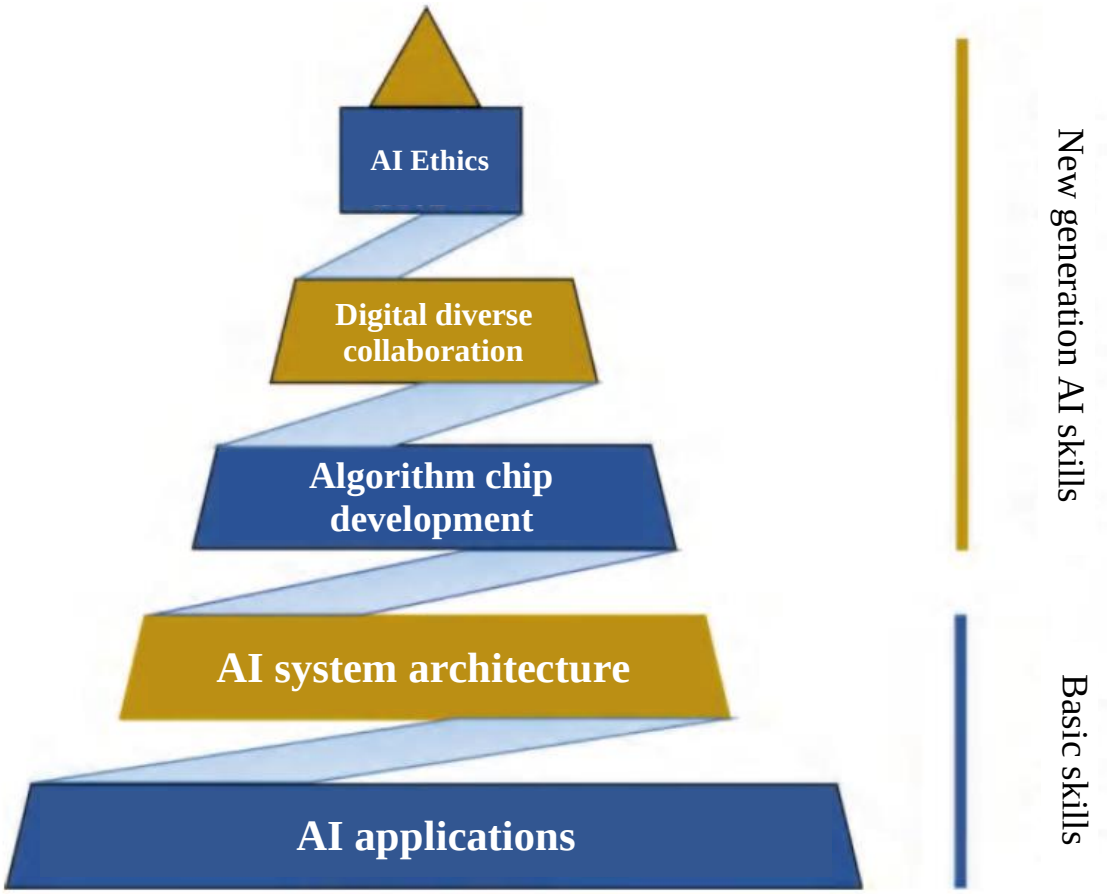


Figure 4.1 A future-oriented model of AI talent competency

2. An AI talent categorization system and its inherent features

The implementation and application of AI is a complex feat of system engineering involving multiple production chain links and requiring a multi-level talent structure. The AI industry is significantly different from traditional industries in terms of both the degree of innovation and the extent of applications. So, compared with the simple development of human resources for traditional industries, job requirements in the AI industry put greater emphasis on the attributes of talents.

In differentiating between different AI talents, they are mainly divided into several major types: solution application type, solution development type, algorithm application type, and algorithm design and development type. The different types of talent have the following capabilities and qualities: **Solution application positions:** Require talents who understand the basic concepts of AI technology and can combine specific use scenarios, assuring the rapid and efficient scaling-up of output and stable operation of AI-related applications. **Solution development positions:** Require talents to combine AI algorithms and technologies (such as machine learning, natural language processing, intelligent speech, computer vision, etc.) with industry requirements to achieve the engineering implementation of relevant applications. **Algorithm application and research positions** (involving algorithm applications, chips, development, and algorithm design and development): Require talents to innovate and make

breakthroughs in AI algorithms and technology research, and combine cutting-edge AI theory with development of practical AI algorithm models.

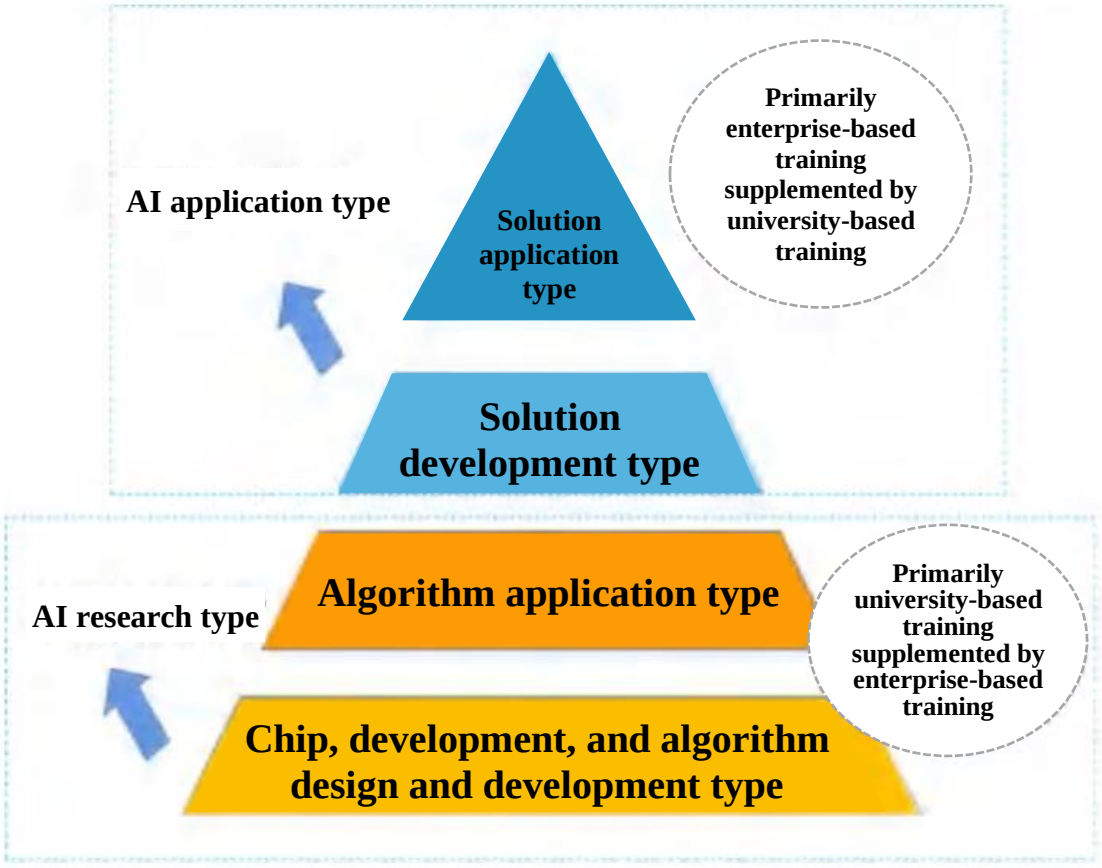


Figure 4.2 Types of AI talents and their development models

Based on the characteristics of AI talent types, the research team divided AI talent training into two talent categories: basic research talents and scenario application talents. Basic research talents mainly include algorithm application, chip, development, and algorithm design and development talents, and scenario application talents mainly include solution application and solution development talents. Definition of AI basic research talent training: Mainly covers the development of AI industry innovation research talents and original innovation talents. Such talents are devoted to basic science research and developing cutting-edge technology, and they determine the technology boundaries of the future AI industry. Definition of AI scenario application talent training: Mainly covers the training of practical skills talents and application development talents. Such talents contribute to industrial application development and practical skills development, and they determine the development scale of AI applications and the AI industry.

B. Development of Basic Research Talents: Gathering disciplinary resources together to strengthen scientific research cooperation

1. University-based: Relies on disciplinary resources and professional resources

Universities play a key role in the development of AI talents around the world. They are the "high ground" for developing research-oriented AI talents, and they develop AI research-oriented talents through joint construction of academic disciplines, laboratories, and innovation cooperation platforms.

(1) In accordance with the requirements of AI, the university-based cultivation of AI talents exhibits a multidisciplinary character. Among existing academic majors, the main majors (directions) that breed AI technical talents include computer S&T and electronic information engineering. Moreover, in the context of industry integration, universities have also created cross-disciplinary "AI+" majors which cover many professional fields such as computers, mathematics, electronic information, statistics, and psychology. The establishment of AI majors has accelerated the integration of AI with basic education disciplines, helping to train growing numbers of hybrid AI industry talents with multidisciplinary and cross-disciplinary knowledge. Data on demand for majors based on employment websites show that, in the AI field. the top ten most popular majors include computer science and technology, software engineering, mathematics, and applied mathematics.

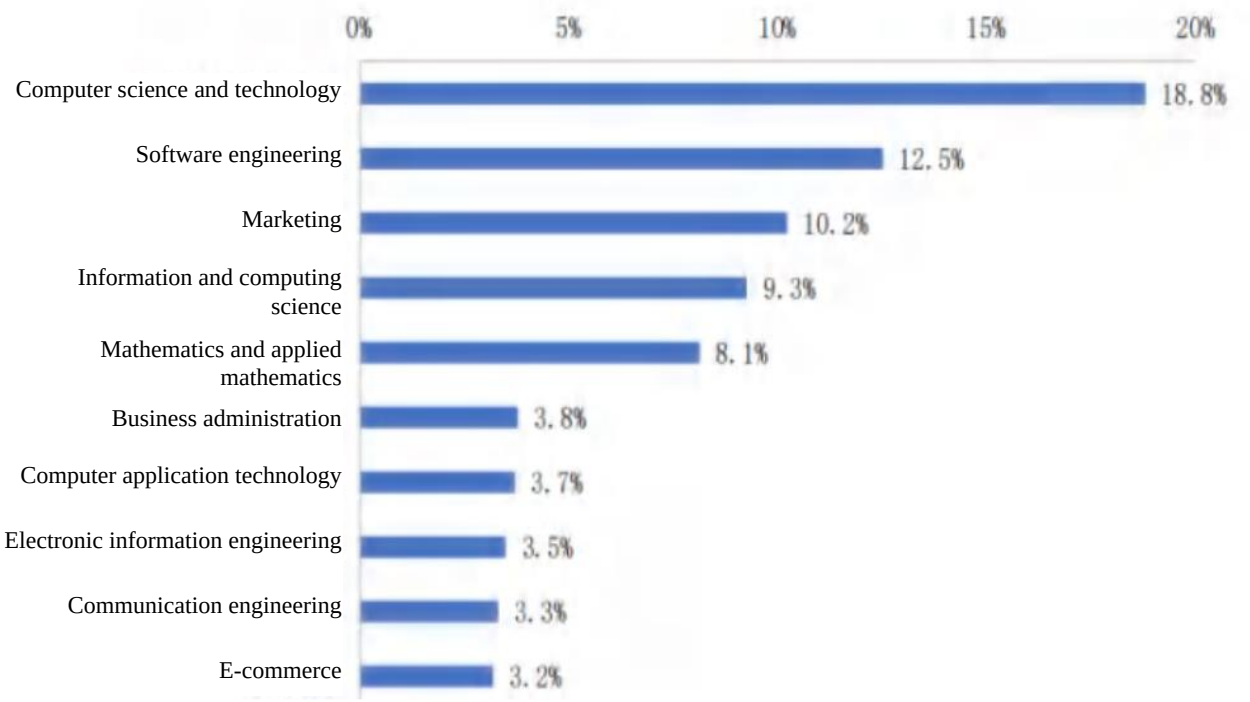


Figure 4.3 Most sought-after majors in the AI industry

Data source: Figure is from *Artificial Intelligence Industry Talent Development Report (2019–2020)*

The cross-fertilization with different disciplines that is characteristic of AI requires universities to develop not only talents who are proficient in only one type of discipline, but also hybrid talents with cross-fertilized knowledge structures, solid specialized skills, and strong social activity ability. From Table 4.1, it can be seen that the curricula of AI majors (directions) basically include common required courses, foundational courses, and core courses, but the course arrangements of different modules differ. Some universities will focus on mathematics course

series in their disciplinary (major) foundation modules, while others focus on the basics of computer theory and artificial intelligence. At most universities, the core courses for majors include machine learning, data mining, image recognition, and other AI applications. Most of the graduate AI majors (directions) are concentrated in schools of computer science, electronic information, and software.

Table 4.1 Curriculum arrangements of graduate AI majors (directions) in five representative universities

School and major (direction)	Course type	Course name
Tsinghua University, Computer Application Technology	Fundamental theory	Stochastic Processes, Combinatorics, Advanced Numerical Analysis, Applied Stochastic Processes, Basic Functional Analysis, Applied Modern Algebra, Modern Optimization Techniques, etc.
	Discipline specialized courses	Artificial Intelligence, Core Technology of Big Data Platforms, Digital Image Processing, Computational Intelligence and Robotic Learning, Advanced Machine Learning, Neural and Cognitive Computing, etc.
	Required courses	Entrepreneurial Opportunity Identification and Business Plans, Research Ethics, Engineering Ethics, Graduate Student Academics and Professionalism, Literature Review and Thesis Topic Selection Report, Academic Activities
Nanjing University, Artificial Intelligence	Fundamental theory	Introduction to Computer Theory, Distributed Systems, Advanced Machine Learning
	Foundational courses	Advanced Algorithms, Computer Problem Solving II, Introduction to Distributed Computing Research, Introduction to Machine Learning Theory Research, Introduction to Software Engineering Research, Project Engineering Practice
	Core courses	Distributed Data Processing, New Database Technology, Computer Graphics, Neural Networks and Their Application, Computational Intelligence, Combinatorics, Computer Vision Theory and Application, etc.
Sun Yat-sen University, Computer Application Technology	Fundamental theory	Theoretical Foundations of Computer Science and Technology, Lectures in Cutting-Edge Computer Science and Technology
	Specialized courses	Numerical Analysis, Stochastic Processes, Matrix Analysis, Quantum Computing, Digital Image Processing, Distributed Operating Systems, Data Mining, Artificial Intelligence and Pattern Recognition, etc.
	Elective courses	Programming Theory, Software Architecture, Advanced Database Technology, Embedded Media Technology, Visual Modeling Methods and Technology, Virtual Reality, etc.
Huazhong University of Science and Technology, Computer Application Technology (Artificial Intelligence)	First-level discipline (一级学科) foundational courses	Matrix Theory, Stochastic Processes, Advanced Computer System Architecture, Modern Computer Networks, Parallel Processing, etc.
	Second-level discipline (二级学科) foundational courses	Artificial Intelligence, Information Storage Theory and Technology, Basic Theory of Computing, Software Engineering Methods, Computer System Analysis and Performance Evaluation, etc.

School and major (direction)	Course type	Course name
	Elective courses	Computer System Design, Computational Intelligence, Database Security Theory and Technology, Machine Learning, Biomedical Image Processing, Computer Vision, etc.
Harbin Institute of Technology, Artificial Intelligence and Pattern Recognition	Discipline foundation and specialized courses	Theory of Computing, Algorithm Design and Analysis, Principles and Applications of Artificial Intelligence, Principles of Database Systems, Natural Language Processing, Pattern Recognition, Machine Learning, etc.
	Elective courses	Computer Vision, Machine Translation, Deep Learning Techniques, Sensor Information Fusion and Its Applications, Complex Networks and Their Visualizations, etc.
	Special topic courses	Network Computing, Multi-Agent Systems, Multimedia Security, Social Computing, etc.

Reference: Li Jun, Chen Wanming, and Dong Li, "Research on Graduate Student Training Approaches in the Context of 'New Engineering' Construction" [J]. *Academic Degrees and Graduate Education*, 2021 (02): 29-35.

(2) Officially including AI industry majors in the list of undergraduate majors has accelerated the process of developing specialized talents for the AI industry. On the basis of traditional electronic information, computer, and mathematics majors, in March 2019, the Ministry of Education issued the *Notice on the Results of Filing and Approval of Undergraduate Majors in Ordinary Institutions of Higher Education in 2018*. AI was included in the list of newly approved undergraduate majors, with 35 universities nationwide receiving the first batch of construction qualifications. In February 2020, the Ministry of Education issued the *Results of Filing and Approval of Undergraduate Majors in Ordinary Institutions of Higher Education in 2019*, with the number of universities that received approval for newly added AI majors reaching 180. In 2021, the Ministry of Education issued the *Results of Filing and Approval of Undergraduate Majors in Ordinary Institutions of Higher Education in 2020*, and 130 universities received approval for newly added AI majors. A total of 345 undergraduate AI majors have been established thus far, and despite being slightly lower than the number of the previous year, it has still attracted the attention of universities. The new AI undergraduate institutions include traditional universities (e.g., Beihang University, Beijing Institute of Technology, Harbin Institute of Technology, Zhejiang University, Nanjing University, Shanghai Jiao Tong University, Fudan University, Tongji University, and Wuhan University), as well as new institutions such as Anhui Institute of Information Technology, Quanzhou University of Information Engineering, East China University of Technology, etc. Universities at different levels are working together to promote the development of AI basic research talents and application-oriented talents.

(3) Universities establishing AI schools and institutes are focusing on training talents oriented toward basic research and application development. In addition to establishing AI majors, various types of domestic universities have started to establish AI schools and research institutes during this period. Top domestic universities such as Peking University, Tsinghua University, Zhejiang University, and Fudan University have established AI teaching and research institutions focusing on basic AI research, including mathematical and scientific foundations, cognitive science foundations, intelligent perception, machine learning, brain-inspired computing (类脑计算), AI governance, smart healthcare, and smart society. The aim is to cultivate and produce research talents with the ability to do basic research in AI. Many domestic undergraduate

universities and colleges have also started to plan and build AI schools and research institutes. By linking up with leading enterprises in various parts of the AI industry chain, such as Baidu, Tencent, and iFlytek, they have strengthened cooperation in talent training, practical training courses, project sharing, and practice opportunities, with the focus on training application development talents with practical experience in AI.

Table 4.2 AI schools and institutes established by universities (partial list)

"Double first class" universities (partial list)	Ordinary universities (partial list)
Peking University – Institute for Artificial Intelligence, School of Artificial Intelligence	Shanghai University of Electric Power – Lin'gang Artificial Intelligence Institute
Tsinghua University – Institute for Artificial Intelligence	Anhui Institute of Information Technology – School of Big Data and Artificial Intelligence
Zhejiang University – Artificial Intelligence Collaborative Innovation Center	Chongqing University of Posts and Telecommunications – College of Artificial Intelligence
Fudan University – Institute of Science and Technology for Brain-inspired Intelligence	East China Jiaotong University – Institute of Artificial Intelligence
Harbin Institute of Technology – AI Research Institute	Dongbei University of Finance and Economics – School of Data Science and Artificial Intelligence
Huazhong University of Science and Technology – School of Artificial Intelligence and Automation, Institute of Artificial Intelligence	Sichuan University Jinjiang College – School of Artificial Intelligence
Tongji University – Artificial Intelligence Institute	Nanning University – [iFlytek] School of Artificial Intelligence
Shanghai Jiao Tong University – [Suzhou] Institute of Artificial Intelligence	Hangzhou Dianzi University – Baidu Cloud School of Artificial Intelligence
School of Artificial Intelligence, Nanjing University	Henan Finance University – College of Artificial Intelligence
Nankai University – College of Artificial Intelligence	Shenzhen University and Tencent Cloud – College of Artificial Intelligence
Jilin University – School of Artificial Intelligence	Liaoning Technical University and Tencent Cloud – School of Artificial Intelligence
Dalian University of Technology Artificial Intelligence Institute	Shandong University of Science and Technology and Tencent Cloud – School of Artificial Intelligence
Xi 'an Jiaotong University – College of Artificial Intelligence	Liaocheng University and Tencent Cloud – College of Artificial Intelligence
School of Intelligent System Engineering, Sun Yat-sen University	Dongying Vocational College of Science and Technology – Artificial Intelligence Institute
Beijing Institute of Technology – Institute for Artificial Intelligence	Hefei College of Finance and Economics – Institute of Artificial Intelligence
Tianjin University – School of Artificial Intelligence	Bozhou Vocational and Technical College – School of Artificial Intelligence
University of Chinese Academy of Sciences – School of Artificial Intelligence	Fuzhou Polytechnic – Baidu Cloud Artificial Intelligence Application Technology Collaborative Innovation Center and Baidu ABC Institute (school of artificial intelligence)
China University of Petroleum (Beijing) – College of Artificial Intelligence	Nanning College for Vocational Technology – School of Artificial Intelligence
Institute of Artificial Intelligence, University of Science and Technology Beijing	Hunan Vocational College of Technology – Artificial Intelligence Institute

"Double first class" universities (partial list)	Ordinary universities (partial list)
Beijing University of Posts and Telecommunications – School of Artificial Intelligence	Shenzhen Polytechnic – School of Artificial Intelligence, Institute of Applied Artificial Intelligence of the Guangdong-Hong Kong-Macau Greater Bay Area
Beijing Jiaotong University – School of Artificial Intelligence	Zhengzhou Vocational College of Commerce and Tourism – Artificial Intelligence Institute

Data source: *Artificial Intelligence Industry Talent Development Report (2019–2020)*

2. Supplemented by enterprises: Strengthening practical teaching and R&D cooperation

Enterprises offer a mastery of the AI industry's key data and cutting-edge directions, which are critical levers for developing research-oriented AI talents.

(1) Provision of teaching materials and massive data (海量数据) is helping universities teach in depth. Unlike in traditional school-enterprise cooperation in the past (helping teaching through lectures, engineer classes, etc.), today's high-tech enterprises tailor-make teaching platforms directly for universities, starting from their immediate teaching needs. The underlying reason for this model is that, AI being a "high-threshold" profession, teaching of AI can only be really promoted if teachers are provided teaching content, derived from industry practice, that meets their urgent teaching needs; otherwise, the teaching of AI will only amount to theoretical discussion. AI without adequate data is like "cooking without a kitchen" (无米之炊), so it is usually necessary to rely on large amounts of data for training in the AI talent training process. Companies like Baidu, Tencent, Alibaba, and Huawei have contributed large quantities of data to universities to help their AI talent teaching.

Table 4.4 The massive data resource advantages of some Chinese S&T-oriented enterprises

Enterprise	Data platforms provided for universities
Baidu	Baidu Brain (百度大脑) and PaddlePaddle industry-level open-source and open deep learning platform
Tencent	Tencent AI Open Platform, Tencent Cloud Smart Education
Alibaba	AlibabaCloud Open Platform
Huawei	Huawei HiAI open data platform

Data source: Compiled based on online materials

Table 4.5 AI teaching resource systems published jointly by enterprises and universities

Enterprise	Features	Teaching materials
Baidu	Publishes AI books and teaching materials at all-levels for K-16	*Machine Learning Practice*, *Computer Vision Practice*, *Natural Language Processing Practice*, *Learn AI with the Great Sages: AI from intro to experiments*, *Beacon Fire Boys AI Battle: AI from programming to practice*, *Kunlun Ziya AI Training: Artificial intelligence from development to real practice*, *Deep Learning: Introduction and application practice*, *Practice Deep Learning from Scratch*, etc.
Huawei	Develops AI practical teaching materials for multiple scenarios	Tentative names of textbooks: *Fundamentals of Artificial Intelligence*, *Machine Learning*, *Deep Learning*, *Computer Vision*, *Natural Language Processing*, *Mobile AI APP Development*, etc.

Alibaba	Puts out textbook series on AI and cloud computing	*Cloud Security: Principle and practice*, *Cloud Computing: Principle and practice*, *Hands-on Cloud Operation and Applications Tutorial (Basic)*, *Hands-on Cloud Operation and Applications Tutorial (Enhanced)*, etc.
Tencent	Has built an integrated industry-education AI teaching material system	*Graphically Illustrated Artificial Intelligence*, *Machine Learning Application*, *AI and Deep Learning: Development and applications*

(2) School-enterprise joint construction of practical training bases

Joint construction of practical training bases promotes academic curriculum construction in universities. With the AI talent deficit in the new wave of AI development being as high as one million talents nationwide, the Ministry of Education and two other ministries have issued a document calling for accelerated development of AI graduate students, and in two years the Ministry of Education has approved hundreds of universities to add AI and big data-related undergraduate majors. However, for the vast majority of universities, AI is a discipline that must be built from scratch. In this context, Chinese enterprises are jointly building AI training bases with universities, signing strategic cooperation framework agreements with universities to integrate their advantages in software platform, practical training, and technical guidance resources, and work together with universities to promote top AI talent cultivation and AI curriculum development. For example, at the 2021 Baidu World Conference, Baidu CTO Wang Haifeng (王海峰) announced the establishment of "Baidu Songguo Academy" ("百度松果学堂") to help develop AI talents in China. Derived from industrial practice, Baidu Songguo Academy is an AI talent training platform which integrates AI basic courses, practical teaching, technical competitions, industrial training, scientific research funds, and other resources. Focusing on various needs of universities and industry, it brings together top academic and industry experts and think tanks from industry and academia, and comprehensively supports AI learning and practice for developers at all stages by means of technology-enabled university education and industry application.

Column 4.1 Cooperating institutions of Baidu AI training bases (partial list)

Baidu has signed cooperation agreements with universities nationwide to integrate supporting resources (e.g., Baidu Songguo Academy), jointly build AI talent training and practice bases with universities, and work with them to promote AI talent training.

Collaboration type	Province	Year	School	Project content	Provided by Baidu
School-enterprise cooperation	Liaoning	2019	Dalian University of Technology	Baidu Songguo Talent Training and Practice Base—AI Talent Training	Baidu Songguo Academy supporting resources
School-enterprise cooperation	Sichuan	2019	University of Electronic Science and Technology of China	Baidu Songguo Talent Training and Practice Base—AI Talent Training	Baidu Songguo Academy supporting resources

Collaboration type	Province	Year	School	Project content	Provided by Baidu
School-enterprise cooperation	Shaanxi	2020	Xidian University	Baidu Songguo Talent Training and Practice Base—AI Talent Training	Baidu Songguo Academy supporting resources
School-enterprise cooperation	Shanghai	2020	Shanghai Jiao Tong University	Baidu Songguo Talent Training and Practice Base—AI Talent Training	Baidu Songguo Academy supporting resources
School-enterprise cooperation	Heilongjiang	2020	Harbin Institute of Technology	Artificial Intelligence Innovation Training Room	Baidu AI teaching and experiment sandbox, Baidu AI body temperature detection system
School-enterprise cooperation	Fujian	2020	Xiamen University	Baidu Songguo Talent Training and Practice Base—AI Talent Training	Baidu Songguo Academy supporting resources
School-enterprise cooperation	Beijing	2020	China Agricultural University	Baidu Songguo Talent Training and Practice Base—AI Talent Training	Baidu Songguo Academy supporting resources
School-enterprise cooperation	Beijing	2020	Beijing University of Posts and Telecommunications	Baidu Songguo Talent Training and Practice Base—AI Talent Training	Baidu Songguo Academy supporting resources
School-enterprise cooperation	Tianjin	2020	Tianjin University	Baidu Songguo Talent Training and Practice Base—AI Talent Training	Baidu Songguo Academy supporting resources
School-enterprise cooperation	Shandong	2020	Ocean University of China	Baidu Songguo Talent Training and Practice Base—AI Talent Training	Baidu Songguo Academy supporting resources
School-enterprise cooperation	Henan	2020	Soochow University	Baidu Songguo Talent Training and Practice Base—AI Talent Training	Baidu Songguo Academy supporting resources
School-enterprise cooperation	Hubei	2020	Central China Normal University	Baidu Songguo Talent Training and Practice Base—AI Talent Training	Baidu Songguo Academy supporting resources
School-enterprise cooperation	Chongqing	2020	Chongqing University	Baidu Songguo Talent Training and Practice Base—AI Talent Training	Baidu Songguo Academy supporting resources

Collaboration type	Province	Year	School	Project content	Provided by Baidu
School-enterprise cooperation	Beijing	2021	Beijing Institute of Technology	Baidu Songguo Talent Training and Practice Base—AI Talent Training	Baidu Songguo Academy supporting resources
School-enterprise cooperation	Beijing	2021	Beijing University of Aeronautics and Astronautics (Beihang University)	Baidu Songguo Talent Training and Practice Base—AI Talent Training	Baidu Songguo Academy supporting resources
School-enterprise cooperation	Shaanxi	2021	Northwestern Polytechnical University	Baidu Songguo Center for Talent Training, Chief Intelligence Officer Class	Baidu Songguo Academy supporting resources
School-enterprise cooperation	Shanghai	2021	East China Normal University	Baidu Songguo Talent Training and Practice Base—AI Talent Training	Baidu Songguo Academy supporting resources
School-enterprise cooperation	Jiangsu	2021	Southeast University	Baidu Songguo Talent Training and Practice Base—AI Talent Training	Baidu Songguo Academy supporting resources
School-enterprise cooperation	Shaanxi	2021	Xi'an Jiaotong University	Baidu Songguo Talent Training and Practice Base—AI Talent Training	Baidu Songguo Academy supporting resources
School-enterprise cooperation	Liaoning	2021	Northeastern University	Baidu Songguo Talent Training and Practice Base—AI Talent Training	Baidu Songguo Academy supporting resources

(3) Promoting research through joint projects and bases

- **Baidu: In-depth cooperation with universities and industry associations**

Since 2013, Baidu has been establishing long-term partnerships with relevant universities and academic organizations such as the China Computer Federation, the China Software Industry Association, the Information Technology Industry-Academia-Research Institute Alliance for New Engineering (信息技术新工科产学研联盟), the Computer Practical Education Committee of China, the China Society for Industrial and Applied Mathematics, and the Society of Management Science and Engineering of China. As one of the first enterprises in the country to launch university-industry cooperation, Baidu, has proven in practice that strategic-level partnerships play a positive role in promoting such cooperation.

Column 4.2: Baidu-USTC Strategic Cooperation

In July 2015, Baidu and the University of Science and Technology of China (USTC) signed a strategic cooperation agreement to carry out in-depth cooperation based on Baidu's leading technology, top expert resources and brand influence, and USTC's influence in academia. Relevant resources and platform support are provided to jointly explore and jointly build a scientific, effective, and complementary innovation and entrepreneurship training ecosystem for college students. The cooperation includes: innovation and entrepreneurship (IE) summer camp, IE counseling mechanisms, IE curriculum system, and innovation talent selection and development.

Cooperation output example 1: Baidu-USTC Student Entrepreneur Growth Program: Stars and experts gather to build the innovation and entrepreneurship talent training ecosystem. Framed within the "National Innovation Plan" initiated by the Ministry of Education, Baidu and USTC jointly launched an innovation, creativity, and entrepreneurship training camp for college students in 2015. Four sessions have been held, for which 3,000+ students registered, and a total of 500+ students participated, representing over a hundred universities (including ones in Hong Kong and Macau), and producing hundreds of AI innovation and entrepreneurship works.

Cooperation output example 2: Baidu-USTC co-construction of the National Engineering Laboratory for Brain-Inspired Intelligence Technology and Application. In January 2017, the National Development and Reform Commission (NDRC) approved two intelligence-oriented national engineering laboratories. One, the National Engineering Laboratory of Deep Learning Technology and Applications, is led by Baidu, and was inaugurated at Baidu on March 2, 2017. The other is the National Engineering Laboratory for Brain-Inspired Intelligence Technology and Application (NEL-BITA), a national engineering laboratory led by USTC, and with Baidu being among the first group of organizations participating in its co-construction. Established in Hefei on May 13, 2017, it is the only national engineering laboratory in the field of brain-inspired intelligence. At the first meeting of NEL-BITA's board, chairman Wan Lijun (万立骏) presented a letter of appointment as vice chairman to Baidu senior vice president Dr. Wang Haifeng.

Cooperation output example 3: As Baidu and USTC's partnership marks its fifth anniversary, they are jointly promoting implementation of scientific research and innovation results through deep integration of industry, academia, and research institutes, furthering China's internet industry development and S&T progress. Since 2012, Baidu and USTC have jointly initiated two research projects that feature industry-academia-research institute integration and involve a wide range of fields, such as internet data, technology, products, and services. The research topics are all cutting-edge research directions in China's internet industry, such as entity search, machine learning, etc. Bringing research results in these cutting-edge fields to fruition will promote S&T progress and development in China.

- **Tencent: Establishment of special research programs and joint laboratories**

CIE-Tencent Robotics X Rhino-Bird Focused Research Program. In order to promote research on cutting-edge issues and key technologies in the field of robotics, promote industry-academia-research institute cooperation, and develop innovative talents, the Chinese Institute of Electronics (CIE) and Tencent jointly established the CIE-Tencent Robotics X Rhino-Bird Focused Research Program (Robotics Rhino-Bird Program; Robotics X 犀牛鸟研究计划; Robotics 犀牛鸟专项). The 2020 Robotics Rhino-Bird Program comprises six research directions

in the field of robotics and is open to applications from institutions of higher learning or public interest research institutes with research directions related to automatic control, mechanical electronics, computers, etc. Tencent Robotics X is Tencent's enterprise-level robotics lab. It is dedicated to researching robotics technologies such as mechatronics, haptic perception, and precision control, and developing next-generation robots that can increase human intellect, enhance human physical capabilities, care about human emotions, and promote human-computer collaboration, thereby creating a win-win future of human-computer coexistence and co-creation.

Tencent joint laboratories program. Tencent has established joint laboratories and comprehensive cooperation platforms with universities (Harbin Institute of Technology, Tsinghua University, the CAS Institute of Computing Technology, Huazhong University of Science and Technology, Peking University, Xi'an Jiaotong University, Nanjing University, and Renmin University of China). It is committed to closely tailoring scientific research to the requirements of industry, and jointly promoting industry-academia-research institute innovation and the practice of industry-academia integration, using the joint laboratories as a platform to integrate the well-positioned resources of both sides.

Table 4.6 Joint laboratories established between Tencent and eight major universities: year established and research directions

Year	Joint laboratory	Research direction
2008	Harbin Institute of Technology-Tencent Joint Laboratory	Founded in 2008, it focuses on technologies such as natural language processing, social media computing, and information retrieval.
2010	Tsinghua University-Tencent Joint Laboratory	Founded at the end of 2010, it focuses on fields such as AI, social networks, massive data, cybersecurity, and internet+ cross-disciplinary innovation technology.
2010	CAS Institute of Computing Technology-Tencent Joint Laboratory	Founded in 2010, it focuses on technical fields such as knowledge engineering, pattern recognition, etc.
2011	Huazhong University of Science and Technology-Tencent Joint Laboratory	Founded in 2011, it focuses on technical fields such as cloud computing and storage.
2017	Peking University-Tencent Joint Laboratory	Founded in 2017, it focuses on big data, multimedia, and other fields of technology.
2018	Xi'an Jiaotong University-Tencent Joint Laboratory	Founded in 2018, it focuses on such technologies as AI and computer vision.
2019	Nanjing University-Tencent Joint Laboratory	Founded in 2019, it focuses on innovative research in AI fields.
2019	Renmin University of China-Tencent Joint Laboratory	Founded in 2019, it focuses on innovative research and application development in the database field.

Rhino-Bird Fund (犀牛鸟基金) established by Tencent. The Rhino-Bird Fund provides the most innovative young scholars around the world with opportunities to understand the real problems of the industry and come face-to-face with actual business requirements. It also helps both sides increase their academic influence and implement application results by connecting young scholars with corporate R&D teams in industry-academia-research institute cooperation, and build up energy reserves for exploration and innovation in independent S&T research and development. As of 2019, the China Computer Federation (CCF)-Tencent Rhino-Bird Fund had

released a total of 124 technical subjects, attracting 1,126 young scholars from 187 universities and research institutions worldwide to submit their research proposals. A total of 141 research fund projects and 108 creative fund projects have received support. Through close cooperation between young scholars and Tencent R&D teams, a total of 784 high-level academic papers have been published, 232 domestic and foreign patents have been applied for, and scientific innovations have been achieved through rolling cooperation.

- **AI research bases established by Alibaba.** On one hand, based on AlibabaCloud AI technology and industry practice, as well as talent training experience, Alibaba Cloud University (阿里云大学) has joined with DAMO Academy and the Machine Learning Platform for AI (PAI) and infrastructure platform teams to upgrade the "Alibaba Cloud AI Academy" (“阿里云人工智能学院”) and provide one-stop AI talent training solutions for universities. With the twin incentives of embracing new infrastructure and addressing AI talent gaps, Alibaba Cloud University has been cooperating with various types of universities at multiple levels, gradually forming a pyramid-shaped three-dimensional education production chain of talent training services, and forming a multi-level ecosystem of new infrastructure construction (新基建), new engineering, new majors, and new models of talent training and learning. On the other hand, Alibaba Group has cooperated with Zhejiang University, Tsinghua University, Alibaba-Nanyang Technological University Singapore Joint Research Institute (南洋理工大学新加坡联合研究院), and other universities to set up professional laboratories and research bases, thereby strengthening the industrial conversion and deep application of scientific research achievements.

C. Development of Scenario Application-Oriented Talents: Strengthening industry-education integration to improve application practice

1. Taking enterprises as the mainstay: Technical training and talent certification

(1) Technical training is an important way to develop application-oriented talents. Development of AI scenario application-oriented talents focuses on combining on-campus and off-campus development, in which enterprises play an indispensable role. AI training carried out by private training institutions is an important supplement for solving the current short supply of AI industry talents. At this stage, the government is focusing on implementing universal intelligence education (全民智能教育), and has also made clear its support for private institutions carrying out AI training.

As for the types of training institutions, at this stage, there are older traditional vocational training schools such as Beida Jade Bird [Vocational Education], Tedu.cn, and Guanghua International [Education], as well as new types of training institutions such as ChinaHadoop.cn (小象学院), shenlanxueyuan.com (深蓝学院), and Gupao Academy (咕泡学院). Training institutions of various kinds have developed a comprehensive AI training approach that combines online and offline teaching methods. As for training content, the AI-related courses of existing training institutions, which focus on training students in application development skills, mainly include three types of courses: Python training, basic introductory AI training, and professional training in AI subsector technology. In addition, at this stage, many institutions have access to the practical experience and practice opportunities of Huawei, Baidu, Alibaba, and other technology giants, and provide students real-world, project-based teaching phase-by-phase. However, due to the lack of mathematical and scientific knowledge course content and short training times, most

of the talents produced by the current training institutions are talents with elementary practical skills.

(2) The series of AI talent certifications established by enterprises has further promoted the development of application-oriented talents. In the face of the huge global AI talent gap, China's leading companies in the AI industry have put out a series of AI talent certifications. For example, Baidu has released Baidu Cloud 2019 ABC talent system certification, defining a new yardstick for AI talent training; and Huawei has launched HCIA-AI certification, HCIP-AI El Developer certification, and HCIP-AI HiAI Developer, for comprehensive certification of AI talents from program application to algorithm research.

2. Colleges and universities as supplementary: talent training systems based on school-enterprise linkage

Whether it is vocational training or talent certification, enterprises play an extremely important role in training application-oriented talents, and in this process, through cooperation with enterprises, universities have achieved applied talent-related technical breakthroughs and have built up talent reserves. Among such enterprises, Baidu, Alibaba, Tencent, and Huawei represent those most prominent in the training of AI application talents.

Figure 4.4 AI solution application-type talent training systems of representative enterprises

Baidu relies on Baidu Songguo Academy to aid AI talent training. Baidu Songguo Academy provides AI course content, popular science books, and fun competitions for primary and secondary school students. For university students, it provides AI courses, technical competitions, and jointly built university practical training rooms and industry schools. For university teachers, it specially arranges AI teacher training and provides a large amount of compute resources to assist teaching by front-line teachers. And for enterprise-based developers, it provides AI courses that are closely integrated with industry, as well as training content on autonomous driving, intelligent cloud, blockchain, and other related segments. Moreover, Baidu Songguo Academy has prepared supporting AI teaching materials for all kinds of people, AI technology application competitions, multi-disciplinary learning communities, and generous learning grants. It plans to work together with 10+ societies, 100+ associations, 1,000+ universities, and 10,000+ enterprises to create a new ecosystem for AI talent training and boost the vitality of China's AI industry development.

Tencent relies on Tencent Education to conduct regular AI talent and teacher training. In order to promote the development of China's AI industry, facilitate the training of professional

talents, and promote the construction of first-level AI disciplines, the Information Technology Industry-Academia-Research Institute Alliance for New Engineering regularly conducts AI teacher training together with Tencent. The training courses are hosted by the Information Technology Industry-Academia-Research Institute Alliance for New Engineering's Data Science and Big Data Technology Working Committee and Teacher Training Working Committee, and is organized by Tianjin University and Tencent. AI teacher training courses were conducted in North China, South China, and Northwest China during October-November 2019, inviting AI field course experts from Tianjin University and industry experts certified by Tencent to teach on-site. This provided in-depth learning and communication opportunities for teachers interested in doing AI education work and training AI talents in universities.

Alibaba relies on the Alibaba Cloud Global Training Center, focused around cutting-edge technology in cloud computing, big data, and AI, to enable university teachers and to help in the construction of new engineering majors. The content mainly involves engineering education concepts, industry scenario-based teaching cases, mixed teaching with senior enterprise experts, co-development of seminars on teaching methods, and Alibaba Cloud authoritative skills certification.

Huawei relies on the Huawei Cloud Developer Academy to provide in-depth learning and communication opportunities for university teachers interested in AI education work and developing AI talents. For AI teacher training, Huawei mainly carries out training for Huawei AI engineers and Huawei enterprise AI senior developers, AI expert classes, and classes for AI senior executives.

Column 4.3: "Huawei Cloud & Beijing University of Technology" user innovation talent training

Beijing Institute of Technology, which is under the Ministry of Industry and Information Technology and directly managed by the central government at the vice ministerial level, was one of the first batch of key universities established after the founding of the People's Republic of China (PRC). It has now been included in the first batch of nationwide "211 Project" and "985 Project" universities, and is one of the first to enter the "Class A" ranks of world-class universities being constructed. The "Huawei & Tech Education (泰克教育) Industry-Education Integration Training Cloud Platform" is an important training base for "cloud computing and big data internship training" in the big data industry. Aiming to enhance students' hands-on practical abilities and career development foundation, it uses real big data scenarios to make up the shortcomings of traditional training rooms.

In order to actively respond to the call to develop new engineering talents, the first national New Engineering Innovation Talent Base (新工科创新人才基地), jointly built by Beijing Institute of Technology, the Information Technology Industry-Academia-Research Institute Alliance for New Engineering, Huawei, and Tech Education Group, was completed in Beijing in September 2018. With technical support provided by an industry-education integrated, cloud-based practice platform, and focused on developing talents oriented towards cloud computing, big data, AI, etc., it is an important initiative for building a Digital China, grasping opportunities in informatized (信息化) development, and truly connecting industry, academia, and research institutes together seamlessly. It therefore has benchmark significance for the construction of an information and communications technology (ICT) talent ecosystem.

Solutions: 1. Creation of a practice environment for cloud computing, big data, etc., that does not need tedious environment building and cleaning, allows access to the experimental environment with one

click, records the practice process at all times, and generates experimental reports automatically. In the experimental process, students can quickly grasp common knowledge points through intelligent question and answer (Q&A), and when they encounter difficult problems, they can also interact with teachers and experts remotely. Finally, the teachers in charge of practical training can understand the students' practice process at any time through the visual management interface, and conveniently access the most realistic and informative practical training reports automatically generated according to specific operations.

2. The platform can simultaneously accommodate the practical training of 200 teachers and students in disciplines such as cloud computing, big data, AI, and data security.

3. It largely eliminates common teaching environment limitations, breaks the ICT industry's teaching bottleneck, achieves a flexible, fast, secure, and money-saving practice model, and can develop more specialized talents highly suited to meeting market demand.

Customer value: 1. Breaks through the previous problems of practical training being heavily formulaic and having low student participation, and is a classic demonstration of a "theory + practice" education solution that combines the virtual with the real!

2. Intelligentized teaching and research, visualized management data, and integration of industry resources greatly improve teaching efficiency and practical training quality.

3. Breaks through the practice bottleneck of traditional teaching, and achieves a flexible, fast, secure, and low-cost practice model.

D. Construction of an integrated government-industry-academia-research institute AI talent ecosystem

1. Differentiation by levels: The foundation for constructing AI talent training models

Along with the deepening implementation of AI applications, the demand for talents has changed from basic research-driven to application-driven, and industry-education integration-based talent training models are plainly important and urgently needed. The State attaches great importance to industry-education integration, and it has actively improved top-level design. In December 2017, the General Office of the State Council issued the *Several Opinions of the General Office of the State Council on Deepening Integration of Industries into Education*; in September 2019, the NDRC issued the *Notice on the Implementation Plan of the National Pilot Program for the Integration of Industry and Education*, which focuses on (1) promoting the better incorporation of industrial requirements in the talent training process, (2) building a system for developing technically skilled talents and innovative and entrepreneurial talents to serve and support the major requirements of industries, and (3) forming a development pattern of overall integration and positive interaction between education and industry. The need for industry-education integration is especially urgent in the field of AI, and the traditional talent training model can no longer adapt to rapidly changing industrial requirements. Against this background, universities can rely on academic research and specialized resources, while enterprises have a firm footing in accumulated practical experience and frontline market demand. Driven by policies and markets, the two are actively building and starting to form an industry-education integration-based talent training model with complementary advantages and resource sharing, and it is gradually developing into a leading force of talent cultivation for the domestic AI industry.

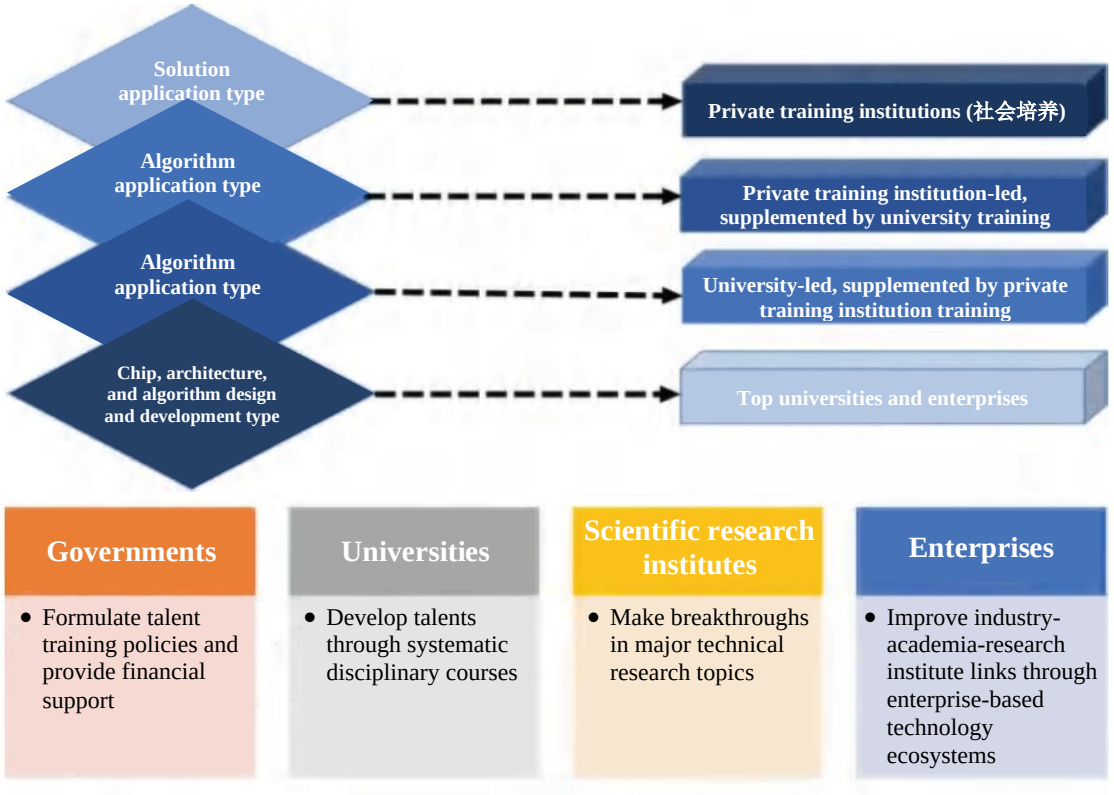


Figure 4.5 Models of differentiated AI talent training in China

2. Industry-education integration: A realistic AI talent training model approach

AI is a basic technology and tool that can disrupt the world's technological development pattern, acting directly on the overlying fundamental layout, and it will play a key role in the future of technological competition. The current trend of AI product development growing increasingly systematized is the product of synthesis between multiple technologies. AI technology is thus poised play a fundamental, pillar-like role. Take autonomous driving technology as an example. Autonomous vehicles rely on the synergistic cooperation of AI, visual computing, radar, monitoring devices, and the Global Positioning System (GPS). It is a comprehensive system that integrates environmental perception, planning and decision-making, multi-level driver assistance, and other functions. By bringing together and utilizing computers, modern sensing, information fusion, communications, AI, and automatic control (自动控制) and other technologies, it is a typical high-tech synthesis. Therefore, future AI talents should have both a deep theoretical foundation and practical application ability. That is, the main goal of AI talent training should be to cultivate application-oriented talents who have both theory and practice. It will have practical problem solving at its core, and will deeply integrate S&T innovation and industrial development. University-based training or enterprise-based training alone is ill-equipped to meet the future trends in AI talent demand, and university-enterprise cooperation in AI talent training has become a strategic choice for major leading AI enterprises and universities of all types and levels. On the one hand, university-enterprise cooperation can promote the integration of industry, academia, research institutes, and users, achieve conversion of scientific research achievements into practical applications (科研成果转化), and increase economic benefits. On the other hand, it can attract more high-level and advanced talents, cultivate application-oriented talents more in tune with AI

fields, and improve the talent pool.

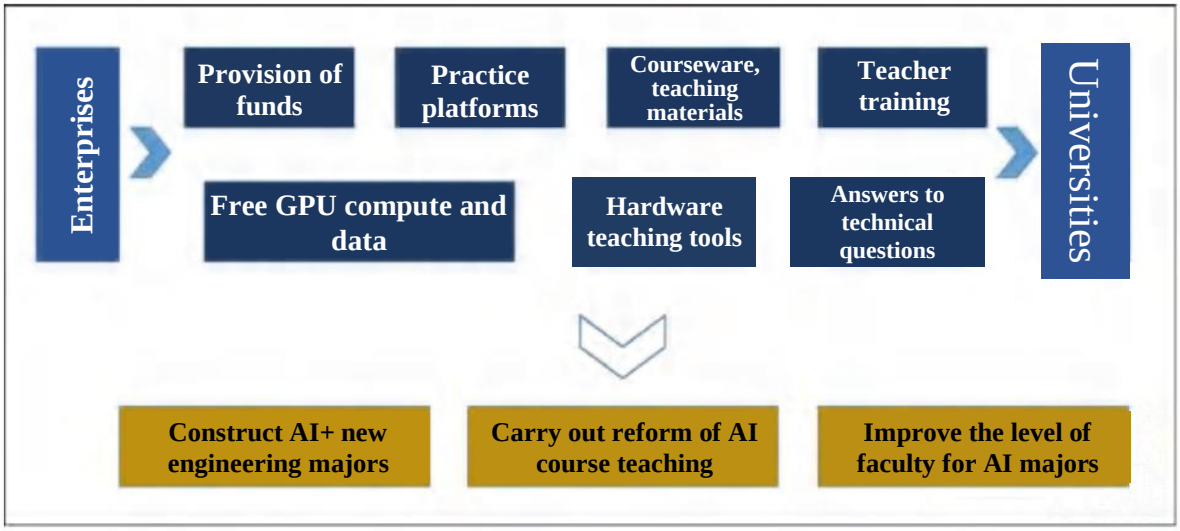


Figure 4.6 Industry-academia collaborative education projects of the Ministry of Education

3. Government guidance: The policy assurance for AI talent training models

The government plays guiding and coordinating roles in the AI talent training process by establishing lasting and effective mechanisms for communication between multiple parties, including government, universities, research institutions, and enterprises. It strengthens the two-way exchange of talents between enterprises and schools, and explores and establishes win-win modes of cooperation. In addition, by strengthening the standardized management of university-enterprise cooperation projects, the government establishes the mainstay status of enterprises in the development of high-level AI talents, clarifies the rights and obligations of enterprises in talent training, strengthens intellectual property protection, and guarantees the rights and interests of enterprises. Through legislative improvements, policy incentives, and mechanism innovations, the government can gradually explore an effective approach that conforms to the inherent laws of talent training and the development requirements of enterprises. This will provide China more solid talent support and intellectual support for seizing the world's S&T cutting edge, and achieving major breakthroughs with pioneering original achievements in the field of AI.

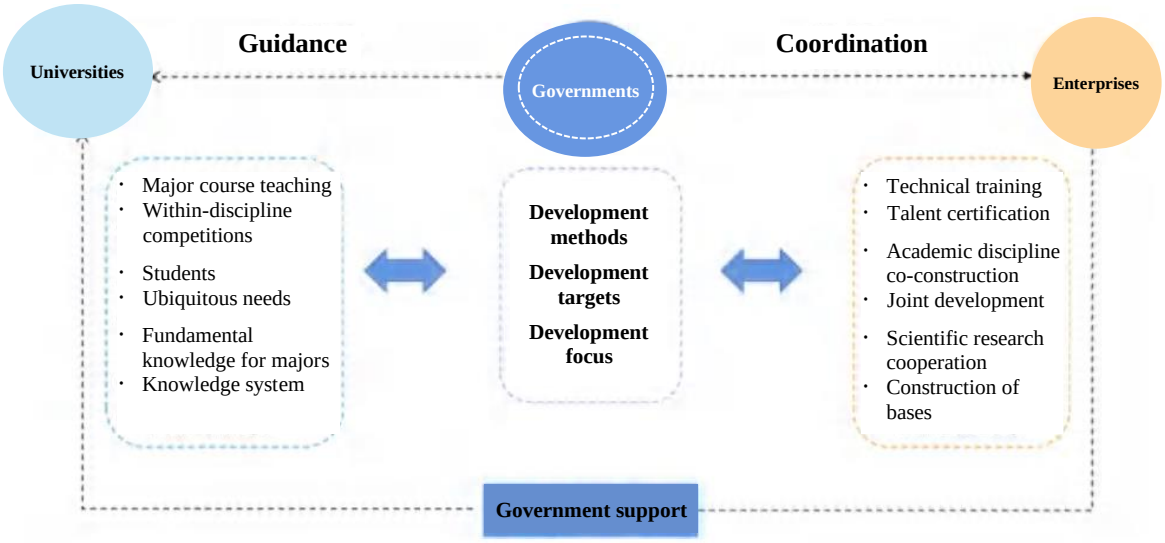


Figure 4.7 Government coordination and guidance of AI talent training trends

E. Building an "AI+" Education Ecosystem of Multiparty Cooperation

Facing the development requirements of China's AI industry, the question of how to ensure the systematic training of AI talents has become an urgent issue to be resolved. With regard to the current situation, whether it is in research-oriented talent training or application-based talent training, enterprises and universities both play important roles, and the integrated government-industry-academia-research institute model of AI talent training is the general trend in the training of high-quality AI talents. Government and industry provide the research directions and funding for talent training, while academia and research institutes develop students' abilities in AI-related thinking, theory, and practice, and finally industry requirements are taken into consideration to put AI into practice and solve the problems of users in industrial sectors. Undoubtedly, the construction of an integrated government-industry-academia-research institute AI training ecosystem will provide inexhaustible driving force for China's development of high-end AI talents, and for China's "high-quality development."

In the government-industry-academia-research institute integrated AI education ecosystem, enterprises, universities and governments are the core players, and four platforms—AI discipline construction, AI curriculum development, AI platform construction, and the AI learning community—are important dimensions of the "AI +" education ecosystem. Strong AI industry enterprises are taking the initiative to join with universities, research institutes, and professional associations in carrying out AI talent training work by setting up research projects and providing research funds, while the government and other main oversight departments (主管部门) provide institutional support and production chain-related industry enterprises cooperate to build the "AI+" education ecosystem. In terms of developing basic research-oriented talents, universities are the main field of action. The construction of AI-related majors and disciplines in China is still at an early stage, but it is gradually becoming clear that development will be characterized by a focus on training basic talents such as those in algorithm development. Universities should promote the development of research talents through discipline construction, scientific research innovation, practical training, and so on. When it comes to scenario application-oriented talent training, both

on-campus and off-campus development are indispensable, and enterprises should assume a more critical role. The off-campus development of AI application-oriented talents in China relies on large enterprises to disseminate advanced technical concepts and a rich variety of industry practice cases, to provide open labs and public courses for a wide range of learners, to provide external corporate training and technical training, to build a new professional certification system, and to empower the technical development and talent delivery of AI-oriented small and medium-size enterprises.

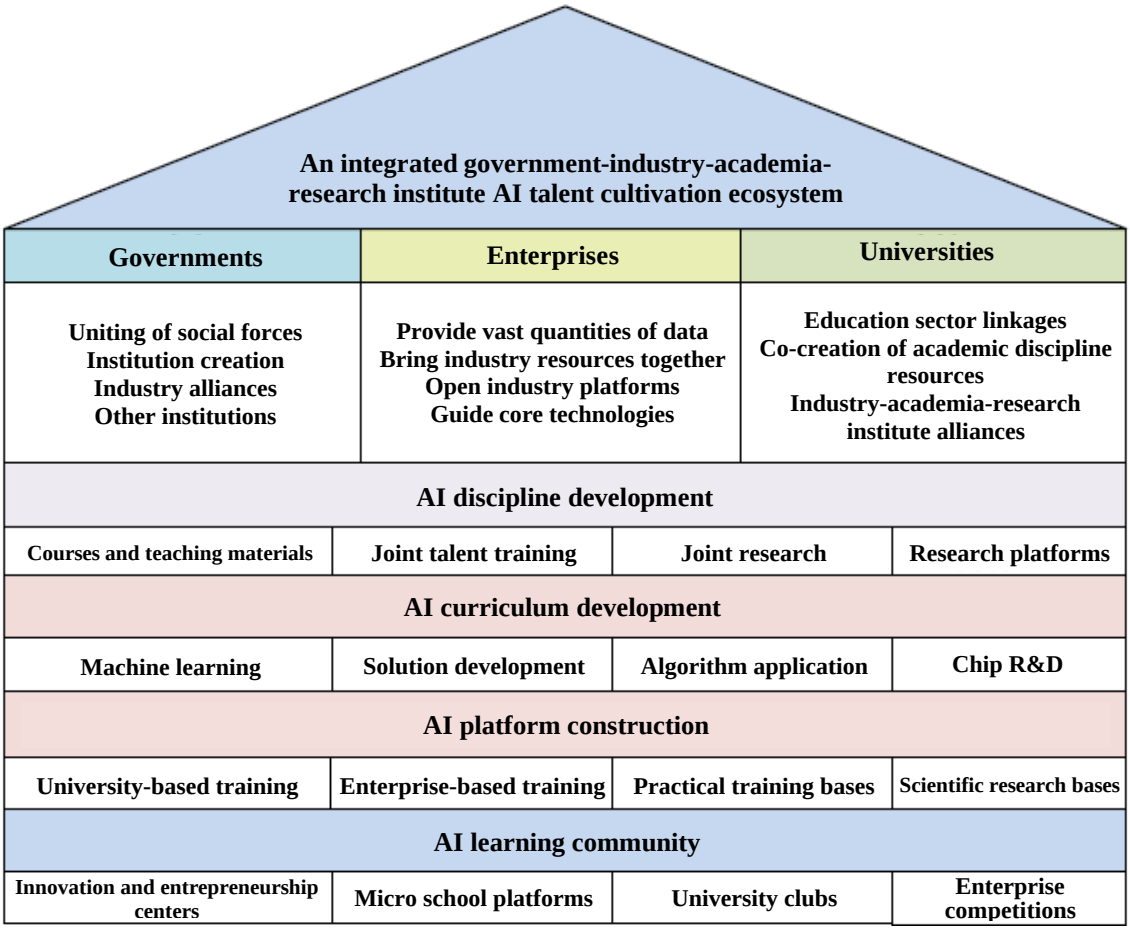


Figure 4.8 An integrated government-industry-academia-research institute AI talent training system

V. Policy Recommendations

Artificial intelligence is a strategic technology leading a new round of S&T revolution, industrial transformation, and social transformation. It has major and profound impacts on economic development, social progress, and international political and economic patterns. The development of new generation information technology such as big data, the Internet of Things, virtual reality, the metaverse, etc., has accelerated the embedding of AI in the field of education. It has profoundly changed talent training models and market absorption methods, in turn spawning a major change in the form of the innovative "AI+" talent training model. Expanding the scale of AI talent training, innovating AI talent training methods, improving the quality of AI talent

training, and thus promoting the development of AI industry itself, is the inevitable approach for occupying a commanding position in future technology and talent competition, accelerating the completion of China's "high ground" for independent AI innovation, and achieving technological self-reliance (自立自强) in the field of AI. Therefore, this report makes the following recommendations:

A. Build an AI Talent Training System that Serves National Strategies

First, strengthen strategic positioning by raising the status of AI talent training in the education system. We recommend that the Ministry of Education guide national universities and leading AI enterprises to set up a steering committee on AI teaching based on science-education-industry integration, in which the number of experts from industry should be no less than 50%, so as to coordinate and promote the construction of AI talent training systems and standards, and to achieve simultaneous improvement of the quantity and quality of AI talent training. The Ministry of Education, the Ministry of Science and Technology (MOST), and the Ministry of Industry and Information Technology (MIIT) should collaborate on establishing an "Artificial Intelligence Talent Training Expert Committee" to give full play to the leading role of AI subject specialists and industry experts in the AI talent training system, and organize the preparation of a special development plan for national AI talent training covering all stages of schooling and the universal education system. An *Artificial Intelligence Talent Planning Outline* should be introduced at the appropriate time to set AI talent objectives for universal education, including real problem-solving ability, technical scenario application ability, critical thinking and cooperative communication ability, independent learning ability, digital literacy and digital skills, etc. Enterprises should be encouraged to use their advantages—massive data and strength in practical training—to cultivate innovative AI talents through internal training, global deployment, establishment of apprenticeship systems, etc., and accelerate the cultivation of hybrid talents with both good professional quality and core abilities for the application of knowledge in multiple AI scenarios.

Second, highlight differentiation by levels and create a diversified AI talent training model. In the basic education stage, introduce AI science education, and where conditions permit, gradually extend programming education to children. In the higher education stages, differentiation of AI talent training by levels should be emphasized: In higher vocational education and professional education, importance should be attached to the conversion and application of AI technology; undergraduate education should focus on training in the basic principles, methods, and thinking of AI education, promoting hybrid cross-fertilization between AI and other disciplines, emphasizing the broad caliber, deep foundation, and comprehensive and hybrid character of talent training; graduate education should emphasize cultivation of high-level AI talents, attaching importance to the technical aspects of the AI production chain, and stressing the development and use at the technological frontiers of cutting-edge AI sub-fields such as image, vision, speech, natural language processing, and brain science. Universities should be encouraged and supported to open relevant teaching and research resources and platforms to the public, establish public service AI education platforms for the public, and play the leading role in terms of public awareness of S&T resources and facilities.

B. Strengthen Multidisciplinary Cooperation and Establishment of AI Minors

First is education model innovation based on multidisciplinary cooperation in the field

of AI. Increase the policy preference for multidisciplinary talent training in AI, and include cross-disciplinary and compound-type AI talent training and team building in the national medium- to long-term S&T and talent training planning outline, and provide government investment, infrastructure, and other support. Support the construction of "AI+" discipline clusters and of majors with new structures without being limited to simply adding to the training objectives of existing disciplines, implement the concept of "making way for new advances" (“推陈出新”) and focus on the long-term construction of the talent training system. For diversified industry fields, emphasize AI talents' awareness of the connections among key horizontally related areas, create "AI + X" hybrid-type professional training models, and pay attention to the cross-fertilization of AI and mathematics, computer science, physics, biology, psychology, sociology, law, and other professional education disciplines. Incorporate courses such as *Introduction to Artificial Intelligence* into university general education curriculum modules to diffuse knowledge of AI in different disciplines.

Second is multi-departmental collaboration to explore and promote setting up AI minors. Offer minors in AI to students not majoring in AI, so as to promote cross-fertilization of interdisciplinary majors and the construction of “four news”[6] majors. We recommend that universities construct a four-in-one curriculum system of "general courses + major foundation courses + major direction courses + practical courses," specifically including prerequisite courses, foundational courses, module courses, algorithm practice courses, and offline practice courses, and covering the main AI technical directions and typical cross-fertilization application scenarios. Actively carry out offline practical training activities for those minoring in AI, carry out thematic practical training centered around S&T innovation and practical implementation through minoring platforms, open up the boundaries between academia and industry, and achieve systematic training and building of knowledge in different disciplines with AI as the foundation.

C. Rely on Industry Leaders to Build the "AI+X" Education Ecosystem

First, promote the deep integration of AI talent training and industry. Fully integrate high-quality "ubiquitous education" resources from government, universities, industry, and society, develop multi-level cooperative education models and products, and conduct comprehensive cooperation in areas such as collaborative R&D in major courses, experimental and practical training base construction, teacher training, scientific research and development, skill certification, and internship employment. Give full play to the leadership role of leading companies; promote cooperation among various leading enterprises in the AI industry ecosystem, such as terminal manufacturers and those in the advanced manufacturing and information service industries; create a talent training benchmarking model; and use a mature education system that integrates application scenarios to drive the systematic innovation of the AI education ecosystem based on industry-education integration. Set up demonstration areas for industry-education integration-based talent training, with the themes of AI basic theory and industrial applications, in regions with superior conditions such Beijing-Tianjin-Hebei, the Yangtze River Delta, Guangdong, Hong Kong, and Macau, etc., focusing on the major cutting-edge issues and key and core technologies (关键核心技术) in the AI field, so as to cultivate high-level application-oriented

[6] Translator's note: The "four news" (“四新”) refers to the construction of new engineering curricula, new medical curricula, new agricultural curricula, and new humanities curricula (新工科、心医科、新农科、新文科) at Chinese higher education institutions.

talents to serve industrial development. Promote the government-led deep integration of industry, academia, and research institutes, and encourage enterprises, universities, research institutes, etc., to engage in joint AI talent training. Encourage leading AI enterprises to cooperate with universities to develop AI learning courses and AI teaching material (textbook) series, and ensure that the proportion of courses provided by enterprises is not less than 30%, in order to make up for universities' insufficient curriculum development and textbook writing. Support universities in joining with backbone AI enterprises, industrialization bases, and local governments to establish joint talent training programs, establish task-driven cross-industry and cross-disciplinary tutor teams, and promote the development of collaborative innovation in scientific research and the joint training of doctoral students.

Second, based on AI application scenarios, create industry-academia-research institute experiential learning bases. With the Ministry of Education taking the lead, support the establishment of AI industry-academia-research institute alliances to create a number of regional and shared talent training practice bases that will unite education, training, and research. Make use of platforms such as university entrepreneurship incubation bases, S&T innovation and entrepreneurship practice bases, mass innovation centers (众创中心), and makerspaces to carry out in-depth engineering S&T practice activities. Widely promote science-education, industry-education, and school-enterprise integration, and carry out AI practical teaching activities comprehensively and in depth, so that students can get good practical training in a realistic environment both on and off campus. Making comprehensive use of the high-quality data and information resources of leading AI companies, further strengthen training approaches with AI models based on real data situations, thereby serving high-level AI talent training.

D. Explore Construction of a Global Standards System for AI Talent Training

First, actively explore the development of a world-leading AI education standards system. We should strengthen overall planning, accelerate the setting of AI education standards that match industrial systems and industrial technologies, promote the coordination of multifunctional departments such as the Ministry of Education, MOST, MIIT, CAS, the Chinese Academy of Engineering (CAE), and the [China Electronics] Standardization Institute (CESI), taking into consideration national strategic development requirements and future talent training trends, and accelerate construction of the AI talent training standards system. It is recommended that we fully exploit domestic AI data resource advantages, refine the core indicators of AI talent training and evaluation, and, taking standards development as the precursor, fully apply the standards to talent training and evaluation, major projects, and other work practices, so as to make talent training increasingly systematic.

Second, take the initiative to plan the construction of an international AI talent training standards organization. In the field of AI talent training and education, in which China is rather well-positioned, we should actively plan to establish an international standards organization headquartered in China and oriented towards new generation information technology development. Drawing on the operational models and governance structures of mature international standards organizations, and in accordance with the principles of marketization and internationalization, we should initiate the establishment of the standards organization, relying mainly on industry associations or other market-oriented organizations, and win the support of all parties. With the help of the standards organization and platform, we should start to develop global

AI talent training standards, and gradually enhance the voice and influence of China's AI education industry in the development and evaluation of talents in key AI fields. We should adhere to open sharing, use the standards platform to maximize the power of all parties, build consensus among all parties, and jointly formulate talent training standards that meet with the approval of international markets, receive the recognition of enterprises, and satisfy users.

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