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Demand Characteristics and Training Trend of Engineering Science and Technology Personnel Based on Education for Sustainable Development

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Abstract: From the *Agenda for the 21st Century* to the *Education 2030 Framework for Action*, the international community continues to promote education for sustainable development (ESD) and to integrate, reshape, and innovate the existing education systems. The concept of ESD has played a leading role in the reform of international engineering education in the 21st century and is increasingly becoming an important strategic choice to improve the quality of engineering education. In this study, we explore the historical evolution of ESD and analyze the demand characteristics of engineering science and technology personnel supporting ESD in view of 2030 goals; the analysis focuses on the following aspects: new requirements of training objectives and key abilities based on ESD, analysis of the International Engineering Alliance Graduate Attributes and Professional Competencies framework, and China's engineering education reform practice. On the basis of the concept of ESD, we summarize the existing challenges in the training of engineering scientific and technological personnel in China, specifically regarding training orientation, training process design, and student assessment and evaluation. The research indicates that China's promotion of ESD for 2030 should strengthen top-level design to exert policy synergy, promote international cooperation to integrate global high-quality resources, optimize professional layout to maximize the advantages of professional clusters, improve curriculum teaching for training excellent engineering personnel, and strengthen accreditation while improving the quality standards system, thereby promoting the continuous improvement of the quality of engineering science and technology personnel that meet the sustainable development goals.
Keywords: education for sustainable development; engineering science and technology talents; demand characteristics; graduate attribute and professional competency; engineering education

1 Introduction

Education for sustainable development (ESD) integrates sustainable development into education; promotes responsible individual or organizational behavior at the regional or even global level; and strives for the coordinated development of resources, environment, society, and economy, so as to appropriately share resources among different generations and build a beautiful future featuring ecological balance and harmony. At present, it has become a core value vigorously advocated by countries around the world [1]. In engineering education, with the continuous advancement of the Fourth Industrial Revolution, various emerging sciences and technologies, such as artificial

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intelligence (AI) and big data, have transformed the social and economic structure, industrial production, and even our lifestyles. ESD's core value is to greatly ease the contradiction between man and nature, while promoting the sustainable evolution of industry and human civilization through rapid technological advancement.

In this context, one of the vital missions for higher engineering education is training engineering professionals dedicated to sustainable development and promoting its advancement. A survey of more than 260 universities around the world shows that despite widespread acceptance of the concept of sustainable development, students still need considerable improvement in their understanding of the concept, and the accuracy rate of the core subject tests is only about 50% [2]. To this end, this study examines the historical evolution of the ESD concept, analyzes the new requirements of student training goals and key abilities provided by international organizations that promote ESD, and explores the amendments and underlying indications of the Graduate Attributes and Professional Competencies (GAPCs) framework proposed by the International Engineering Alliance (IEA). It also puts forward an effective path for integrating ESD into the whole process of training for engineering professionals in the future.

2 Evolution of ESD

2.1 Beginning stage (1972–1987)

Since the Industrial Revolution, countries around the world have always regarded promoting industrial and economic development as an important strategy to enhance national vitality and improve people's well-being. However, their long-term excessive pursuit of high-speed economic development has led to many problems, including excessive consumption of resources, serious pollution, and a huge gap between the rich and the poor. As a result, the contradiction between people's demand for high-quality living standards and limited material resources has become the focus of social problems in the modern world, which has in turn prompted people to think about sustainable development, leading to the gradual formation of some basic points of consensus around it. Sustainable development is the only way for human civilization to continue in the future and should consist of fair social progress, efficient environmental protection, and responsible economic growth. The Club of Rome, an informal society of futurology established by 30 scientists, educators, and economists from different parts of the world, published a research report titled *The Limits to Growth* in 1972, which was the first proposal to consider economic growth from a global perspective. In the same year, the *Declaration of the United Nations Conference on the Human Environment* put forward a prototype of sustainable development, calling on governments of all countries to make continuous efforts to improve the environment and benefit future generations. Nevertheless, it only focused on environmental protection. Later, the United Nations Educational, Scientific, and Cultural Organization (UNESCO) issued two programmatic documents, namely, *The Belgrade Charter: A Global Framework for Environmental Education* in 1975 and the *Tbilisi Declaration* in 1977 [3], which identified the basic principles and practical paths for global environmental education. The former document clarified the framework of the environmental education concept, and the latter extended its content from the original knowledge-based approach to five areas: knowledge, awareness, attitude, skills, and participation. In 1984, the World Commission on Environment and Development (WCED) was formally established, becoming a global professional organization for promoting environmental education. WCED released *Our Common Future* (also known as *The Brundtland Report*) in 1987 [4], formulating the conceptual framework for sustainable development—which satisfies contemporary needs, without harming the needs of future generations. At this stage, environmental education became a key part of sustainable development, but the overall sustainable development and education, especially the reform of personnel training, was still not interconnected, and the concept of ESD was in its infancy.

2.2 Formation stage (1988–2011)

In the late 1980s, the international community experienced a discourse system change from environmental education to ESD. In 1988, UNESCO integrated environmental education and development education by reconciling the goals, nature, tasks, and content of environmental education. It formally proposed the term "education for sustainable development" (ESD), which has become a matter of increasing international concern [5]. In 1992, the UN Conference on Environment and Development (UNCED) passed *Agenda 21*, covering sustainable development strategy, sustainable social development, sustainable economic development, and rational use of resources and environmental protection. It designed a blueprint for global sustainable development action and emphasized embedding both the environment and development within education at all levels [6]. Since then, integrating the concept of sustainable development into the education system at all levels has become an important means to

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promote ESD [7]. In 2005, the *United Nations Decade of Education for Sustainable Development (2005–2014)* was officially launched, aiming to integrate the concept of sustainable development into education policies and curriculum, raise people's awareness of sustainable development, and strengthen international exchanges and collaborations on sustainability issues. At this time, the concept of sustainable development went well beyond traditional environmental protection, to also cover economic aspects (such as poverty eradication and social accommodation) and socio-cultural aspects (such as gender equality and cultural diversity) [8]. In 2009, the *Bonn Declaration*, issued at the 1st UNESCO World Conference on Education for Sustainable Development, made it clear that efforts should be made to incorporate ESD into the top-level design of states' public policies. In 2010, *Engineering: Issues, Challenges and Opportunities for Development*, the first engineering report by UNESCO, warned of the potential threats and challenges posed by engineering technologies despite their important role in future development and noted that ESD was a powerful tool to cope with the challenges [9]. Engineering ESD covered multiple fields, including economic, social, and technological development. It played a leading role in prescribing the know-how that engineering practitioners should master in the context of the new Industrial Revolution. Generally speaking, in the formative stage, ESD has played a leading role in the reform and development of engineering education. It has increasingly become one of the strategic choices for the development of universities and colleges.

2.3 Refinement stage (2012–now)

The 2012 United Nations Conference on Sustainable Development in Rio (also known as Rio+20) clearly advanced three objectives, namely, the commitment of countries to sustainable development, current challenges and insufficiency, and effective response to continuous challenges, and systematically constructed a global sustainable development framework. Meanwhile, the Higher Education Sustainability Initiative adopted at the event required higher-education institutions to assume more responsibilities and play a greater role in sustainable development. In 2013, UNESCO adopted the *Global Action Programme on Education for Sustainable Development (2015—2019)* [10], aimed at enhancing the international influence of ESD and developing a sound mechanism. The Global Action Programme supported five priority areas simultaneously: advancing top-level policy design, improving the training and learning environment, enhancing staff capabilities, empowering learners, and designing a regional-level program. The World Education Forum 2015 organized by UNESCO was held in Incheon, Republic of Korea, in May 2015. It focused on the overall design of the draft framework of *Education 2030*, noting the importance of education in promoting sustainable development [11]. *Transforming our World: The 2030 Agenda for Sustainable Development*, adopted by the United Nations Summit on Sustainable Development in September 2015, identified 17 sustainable development goals (SDGs); urged the international community to achieve essential breakthroughs within the ensuing 15 years in mitigating climate change, reducing inequality, and curbing extreme poverty; and guided the overall efforts to achieve global sustainable development after the millennium development goals (MDGs) [12]. To further implement the SDGs, UNESCO officially released the *Education 2030 Framework for Action* in November 2015, which mainly consisted of the vision, concepts, and principles for Education 2030; the seven major goals, specific targets, and measurement indicators for global education; and action strategies including a management, monitoring, tracking, and reviewing mechanism [13]. *The Sustainable Development Goals Report 2020* noted that the implementation of SDGs was in good shape before the COVID-19 outbreak; however, the pandemic had eroded global achievements in poverty reduction, education equality, and healthcare development over the previous decade, making the achievement of the SDGs even more challenging [14]. On the whole, the ESD concept, even as it is being refined, has been deeply and widely accepted worldwide, and a systematic, multi-level, and three-dimensional mechanism has formed gradually.

3 Requirements of engineering professionals that support 2030 ESD

3.1 ESD-based training targets and key competences

Since a global consensus has formed around ESD, it has been intertwined with the reform of higher education. In the context of 2030 ESD, the reform of engineering education has two vital goals: one is to re-position the training targets for engineering technology programs, and build a systematic training system based on knowledge, skills and values; the other is to enable learners to master the key competences for achieving sustainable development through continuous training reforms.

ESD focuses on sustainable training based on learners' comprehensive quality, which requires engineering education to construct new training targets and key competences that can promote sustainable development. The training targets for engineering technology programs based on ESD incorporate three levels: knowledge, skills, and values. In terms of knowledge, learners should have a mastery of basic knowledge and professional frontier knowledge so as to better understand the reform goals, current challenges, and solutions for global sustainable development. The skill target refers to the ability to analyze and solve specific issues, aiming to enable learners to cope with the actual problems and challenges in current global sustainable development. The value target mainly includes learners' awareness and value, which means that they are able to think critically and make ethical judgments when solving the problems raised by sustainable development [15]. In general, the overall design of ESD-based training objectives requires the learners to master basic engineering knowledge and professional frontier know-how, highly recognize the value concept of sustainable development, and be able to promote sustainable development by making the most of their learned knowledge and skills.

ESD, which is based on systematic knowledge, skills, and values training, emphasizes that the students trained must be able to comprehensively promote sustainable development and play their part in the sustainable development of a region, country, and even the world. The *Issues and Trends in Education for Sustainable Development* published by UNESCO clearly defines and interprets the eight capabilities: systematic and critical thinking, anticipation, making strategies, abiding by value norms, collaboration, critical thinking, mobility, and self-reflection [16]. This framework is equally important for engineering graduates.

3.2 Content and mechanism of GAPC

Engineering technology plays a vital role in achieving the SDGs for UN 2030 Agenda. To address global challenges and build a community with a shared vision of the future for mankind, engineering technologies from all over the world need to maintain their innovation and advantages, on the one hand, and speed up the establishment of a benchmark framework system in line with globalization, on the other, so as to realize the training goals and key competences for ESD. In terms of engineering education, GAPCs proposed in the early 2000s, have been revised three times, in 2005, 2009, and 2013. The IEA signed a memorandum of understanding with the World Federation of Engineering Organizations in November 2019 and established a professional working group composed of international experts to revise the GAPC, which is the basis for the mutual recognition of engineering education certifications and engineering professional qualifications in more than 30 countries or regions worldwide, including the Washington Accord, Sydney Accord, and Dublin Accord. The basic goals of GAPC revisions are as follows: (1) to reflect changes in social needs and new ideas, review whether the current graduate attributes (GAs) are sustainable for achieving the SDGs, and make sure they cover emerging technologies and frontier knowledge in engineering disciplines; (2) to build an international benchmark for professional competences (PCs), and examine whether graduates and engineering practitioners can meet the needs and expectations of employers, particularly with respect to lifelong learning [17].

The three accords on mutual recognition of accreditation and registration in the field of engineering education, the Washington Accord, Sydney Accord, and Dublin Accord, have different definitions of engineering practitioners (Table 1) [18], on which basis GAPC has set up its own standards for GAs and PCs and formed the basic features of engineering professionals in line with ESD. This study analyzed the content and underlying mechanism of the latest GA and PC requirements, with a focus on ESD-related sections.

Table 1. International accords for mutual recognition of engineering accreditation.

Name	Signing time	Objects	Number of participants
Washington Accord	1989	Professional engineers with a four-year engineering degree	21 official members and 7 candidates
Sydney Accord	2001	Engineering technologist with a three-year bachelor's degree	11 official members and 2 candidates
Dublin Accord	2002	Engineering technicians with a two-year associate's degree	9 official members

3.2.1 GAs

GAs refer to the minimum requirement for engineering graduates to participate in professional qualification programs. Table 2 below has listed some of the requirements for engineering GAs under the Washington Accord, Sydney Accord, and Dublin Accord. Their differences are as follows: (1) In terms of problem analysis, the

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Washington Accord emphasizes that when analyzing complex engineering issues, sustainable development should be taken into overall consideration, which the other two fail to explicitly indicate; (2) In terms of design and development solutions, all three accords incorporate public health and safety, whole-life cost, net-zero carbon emissions, resource reuse, and cultural, social, and environmental factors; (3) In terms of modern tool usage, all three propose to fully consider the limitations of their applications; (4) In terms of the relationship between engineers and society, despite different statements, all three accords require integrating the sustainable development responsibilities into engineering solutions; (5) In terms of the environment and sustainability, all three accords require understanding and evaluating the sustainability and impact of solving complex, broadly defined, and well-defined engineering issues related to humans, culture, the economy, society, and the environment; (6) In terms of ethics, they all require practitioners to abide by rules of professional ethics, technical ethics, data ethics, global responsibility, and engineering practice responsibilities and norms, and comply with national and international laws; (7) In terms of lifelong learning, they all require graduates to commit to continuous learning and develop critical thinking.

3.2.2 PCs

To meet the minimum standards of competence, a person must demonstrate that they are able to practice competently within a practice area to the standards expected of a reasonable professional engineer/engineering technologist/engineering technician. Table 3 lists some of the PC requirements for engineering graduates under the Washington Accord, Sydney Accord, and Dublin Accord. Their differences are as follows: (1) In terms of evaluation, individuals should evaluate the results and impacts of well-defined, broadly defined, or complex activities from the perspectives of risk, resources, and social, environmental, and economic factors; (2) In terms of social protection, they should be aware of the reasonable and foreseeable social, cultural, and environmental impacts of different activities, and endeavor to protect the environment and improve the quality of life in accordance with the UN SDGs; (3) In terms of laws, environment, culture, and regulations, they must abide by all laws and regulations, and assume the responsibility for protecting public health, safety, the environment, and cultural heritage in all activities; (4) In terms of continuous professional development, they should attend related activities to improve their ability to adapt to new technologies and changes; (5) In terms of judgment, they should take social, economic, environmental, cultural, and other factors into consideration.

Generally, GAPC has two vital features: first, it has formulated differentiated and rational GAs and PCs based on the continuity and hierarchy of knowledge production for the different types of engineering practitioners, namely, professional engineers, engineering technologists, and engineering technicians, who focus on solving complex, broadly defined, and well-defined engineering problems, respectively; second, the GAs and PCs of engineering graduates listed in the three accords all emphasize the implementation of the basic goals of ESD, which is highly consistent with the *Education 2030 Framework for Action*.

3.3 China's reform and practice of engineering education based on the sustainable development concept

Since the Industrial Revolution, the mode of large-scale industrial production has greatly promoted advanced material civilization, yet it has also caused a series of problems, such as environmental pollution, resource depletion, ecological degradation, and global warming, which seriously threaten the sustainable development of human civilization. To this end, promoting in-depth transformations of the industrial production models based on the sustainability concept has become the main theme of today's world. The *2030 Agenda for Sustainable Development* issued by UNESCO, proposed 17 SDGs, of which 8 are closely related to engineering ESD. Moreover, *Engineering Grand Challenges for the 21st Century*, issued by the US National Academy of Engineering, listed 14 major engineering challenges, 5 of which are directly related to sustainable development engineering. Higher engineering education has the responsibility to cultivate future engineering professionals, and engineering education should reform itself to adapt to the SDGs. In the era of big science and big engineering, the impact of engineering technology on the economy, society, and environment has become increasingly prominent. In the context of complex environmental issues, ecological resource challenges, and the sudden outbreak of COVID-19, engineering education shall consider how to further improve the quality of engineers and technologists dedicated to sustainable development in the future, which will become an important innovation in the training system.

Table 2. GA requirements (excerpts)

Differentiating characteristics	Washington Accord requires	Sydney Accord requires	Dublin Accord requires
Problem analysis	Identify, formulate, research, and analyze complex engineering problems and reach substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences with holistic considerations for sustainable development.	Identify, formulate, research, and analyze broadly defined engineering problems and reach substantiated conclusions using analytic tools appropriate to the discipline or area of specialization.	Identify and analyze well-defined engineering problems and reach substantiated conclusions using codified methods of analysis specific to their field of activity.
Design and development of solutions	Design creative solutions for complex engineering problems and design systems, components, or processes to meet identified needs with appropriate consideration for public health and safety, whole-life cost, net-zero carbon, as well as resource, cultural, societal, and environmental considerations as required.	Design solutions for broadly defined engineering technology problems and contribute to the design of systems, components, or processes to meet identified needs with appropriate consideration for public health and safety, whole-life cost, net-zero carbon as well as cultural, societal, and environmental considerations as required.	Design solutions for well-defined technical problems and assist with the design of systems, components, or processes to meet specified needs with appropriate consideration for public health and safety, whole-life cost, net-zero carbon, as well as cultural, societal, and environmental considerations as required.
Modern tool usage	Create, select, and apply appropriate techniques to complex engineering problems and recognize their limitations.	Select and apply appropriate techniques to broadly defined engineering problems and recognize their limitations.	Apply appropriate techniques to well-defined engineering problems and recognize their limitations.
The engineer and the world	Within a reasonable decision-making framework, use reasoning methods to evaluate social, health, safety, legal, historical, and cultural issues and sustainability responsibilities related to professional engineering practices while providing solutions to complex engineering problems.	Understand social, health, safety, legal, and cultural issues, as well as sustainable development responsibilities related to engineering practice while solving broadly defined engineering problems.	Understand social, health, safety, legal, cultural issues and responsibilities related to the engineering practices while solving well-defined engineering problems.
Environment and sustainability	When solving complex engineering problems, analyze and evaluate sustainable development impacts to culture, society, the economy, and the environment, etc.	When solving broadly defined engineering problems, analyze and evaluate sustainable development impacts to culture, society, the economy, and the environment, etc.	When solving well-defined engineering problems, analyze and evaluate sustainable development impacts to culture, society, the economy, and the environment, etc.
Ethics	Apply ethical principles and commit to professional ethics, data ethics, global responsibilities and norms of engineering practice, and adhere to relevant national and international laws.	Understand and commit to professional ethics, data ethics, and norms of engineering technology practice including compliance with national and international laws.	Understand and commit to professional ethics, data ethics, and norms of technician practice including compliance with relevant laws.
Lifelong learning	Independent and lifelong learning, adaptability to new and emerging technologies, and critical thinking in the broadest context of technological change.	Independent and lifelong learning, and critical thinking in the face of new specialist technologies.	Recognize the need and have the ability for independent updating in the face of specialized technical knowledge.

Source: http://www.wfeo.org/wfeo-ceie-gapc-consultation/

China's experience of ecological development during its period of development provides an effective solution for the sustainable development of industrial economies today. Since its reform and opening up, China's economy has developed exponentially, but so has the ecological damage. In this context, President Xi Jinping proposed several theories of ecological development and made it clear that "lucid waters and lush mountains are invaluable assets," laying a theoretical foundation for China's ecological development. The *People's Republic of China National Report on Sustainable Development* released in 2012 expounded China's implementation of its sustainable development strategy for the first time. In the same year, the report of the 18th CPC National Congress incorporated ecological development into the Five-sphere Integrated Plan for building socialism with Chinese characteristics and promoted coordinated progress in the economic, political, cultural, social, and environmental fields. *Opinions of the CPC Central Committee and the State Council on Accelerating the Ecological Civilization Construction* issued in 2015 proposed to coordinate the advancement of new industrialization, informatization, urbanization, agricultural

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modernization, and greening, and regarded greening as a means and evaluation standard for measuring ecological progress. In terms of practice, it advanced the principle of respecting and following nature, giving priority to conservation, protection, and natural restoration, and adopting a path committed to green, circular, and low-carbon development. The *National Plan on Implementation of the 2030 Agenda for Sustainable Development* released in 2016, elaborated on the opportunities and challenges faced by China in advancing the United Nations 2030 Sustainable Development Goals, as well as guidelines, basic principles, overall path, and plans for implementation. *China's Education Modernization 2035*, issued by the Communist Party of China Central Committee and the State Council in 2019, marked another major national strategy for China's active participation in global governance in education and to fulfill its commitment to the UN 2030 Agenda for Sustainable Development. *China's International Development Cooperation in the New Era* released by the State Council in 2021, explained how to support other countries' development through multiple avenues of international cooperation or assistance in eight areas to further promote the effective implementation of the UN 2030 Agenda for Sustainable Development, covering poverty eradication, quality education, gender equality, and sustainable and innovative economic growth, etc. China's ecological progress has been highly recognized by the international community, offering a direction and path for the transformation toward environmentally based sustainable development for the rest of the world.

Table 3. PC requirements (excerpts).

Differentiating characteristics	Washington Accord requires	Sydney Accord requires	Dublin Accord requires
Evaluation	Evaluate the outcomes and impacts of complex activities in the context of risk, society, the environment, the economy, and resources.	Evaluate the outcomes and impacts of broadly defined activities in the context of risk, society, the environment, the economy, and resources.	Evaluate the outcomes and impacts of well-defined activities.
Protection of society	Recognize the foreseeable social, cultural, and environmental effects of complex activities and seek to achieve "no one is left behind" and improve the global living environment and quality of life based on UN SDGs.	Recognize the foreseeable social, cultural, and environmental effects of broadly defined activities and seek to achieve "no one is left behind" and improve the global living environment and quality of life based on UN SDGs.	Recognize the foreseeable social, cultural, and environmental effects of well-defined activities and seek to achieve "no one is left behind" and improve the global living environment and quality of life based on UN SDGs.
Legal, cultural, and regulatory	Meet all legal and regulatory requirements and protect public health and safety in the course of all activities.	Meet all legal and regulatory requirements and protect public health and safety, in the course of all activities.	Meet all legal and regulatory requirements and protect public health and safety, in the course of all activities.
Continuing professional development (CPD)	Undertake CPD activities to maintain and extend competences and enhance the ability to adapt to emerging technologies and the ever-changing nature of work.	Undertake CPD activities to maintain and extend competences and enhance the ability to adapt to emerging technologies and the ever-changing nature of work.	Undertake CPD activities to maintain and extend competences and enhance the ability to adapt to emerging technologies and the ever-changing nature of work.
Judgment	Recognize complexity and assess alternatives in light of competing social, economic, environmental, cultural, and other requirements, and incomplete knowledge. Exercise sound judgment in the course of all complex activities.	Choose appropriate technologies to deal with broadly defined problems in light of social, economic, environmental, and cultural factors. Exercise sound judgment in the course of all broadly defined activities.	Choose and apply appropriate technical expertise. Exercise sound judgment in the course of all well-defined activities.

Source: http://www.wfeo.org/wfeo-ceie-gapc-consultation/

Higher-education institutions are the main bodies for practicing engineering ESD. Some Chinese colleges and universities have engaged in positive explorations as part of their reforms, such as setting up sustainable development-oriented research projects in engineering disciplines, focusing on the integration of related knowledge and concepts in teaching, developing special books or teaching materials, and organizing special associations. Since 1998, Tsinghua University has successively opened a number of new courses in this regard, such as Environmental Protection and Sustainable Development, Fifteen Lectures on Ecological Civilization Construction, Environmental Ethics, Industrial Ecology Theory, and courses related to green industries. These efforts have raised students' awareness of sustainable development, enriched their vision, and improved their engineering innovation, thereby enhancing China's international competitiveness in engineering education. Furthermore, the university has taken active efforts to build a communication platform for integrating industry, academia, and research, so as to promote engineering ESD in China. In response to China's establishment of a sound green and low-carbon circular development economic system, it is necessary to accelerate the training of future-oriented and all-around professionals, enhance the comprehensive strength of Chinese engineering education and basic scientific research, and contribute wisdom and strength to support the national development strategy and innovation.

4 Present challenges faced by ESD-based training of engineering professionals

The new Industrial Revolution not only affects the evolutionary trajectory of engineering education as a whole; it also raises the bar for the supply of engineering practitioners, which requires China to transform the content, methods, and forms of engineer training. At present, engineering education in China faces various challenges in terms of its training goals, processes, and evaluations, and it is necessary to take more measures to meet the requirement for engineers and technicians for 2030 ESD.

4.1 Training targets orientation: contradiction between tool rationality and value rationality

The training objectives of engineering professionals are essentially twofold: knowledge application and knowledge construction. The former focuses on advancing the industry development, which reflects the use value of the discipline, or tool rationality, while the latter emphasizes the inheritance and accumulation of knowledge itself, which defines the connotation boundary of the discipline, or value rationality. The engineering training programs in China, which are based on ESD, should strike a balance between the tool rationality and value rationality. In other words, they should not only serve the needs of national economic and social development, but also comply with the objective law of education. Owing to the mixed influence of many factors, such as academic capitalism and university ranking since the end of the 20th century, universities have been forced to go beyond the traditional ivory tower to engage more in teachings and scientific research that meet market demand and focus on technology applications. In addition, in recent years, many colleges and universities have substantially increased "hot" majors, such as AI, big-data science, and Internet of Things, and abolished unpopular ones. Consequently, the discipline structure has become unbalanced, and education can become utilitarian, which is not conducive to the overall development of qualified engineering practitioners.

4.2 Training processes design: contradiction between theoretical study and practical ability

Developing the complex engineering competence of engineering professionals is a requirement clearly stated in the GAPC, which is based on ESD. In the future, engineers and technicians will be in demand not only for their theoretical knowledge, but also for their practical ability to solve problems. Fig. 1 is a diagram of the training path of engineering practitioners [19]. The quality threshold curve represents the basic criteria for the training programs. Different schools or professions can develop along their own trajectories, or cross with other trajectories in multiple directions. The three different types of training directions, namely, academic-oriented, practice-oriented, and compound (academic–practice balance), reflect the diversity of the national engineering science and technology training. From the perspective of future trends, the compound type (academic–practice balance) is more in line with engineering training requirements in China based on the concept of ESD. However, the current design of the engineering training programs in China is mostly based on a wide-caliber general education concept, focusing too much on the training of academic knowledge and ignoring the ability to solve practical problems, which makes it difficult for students to gain access to complex real-world engineering problems.

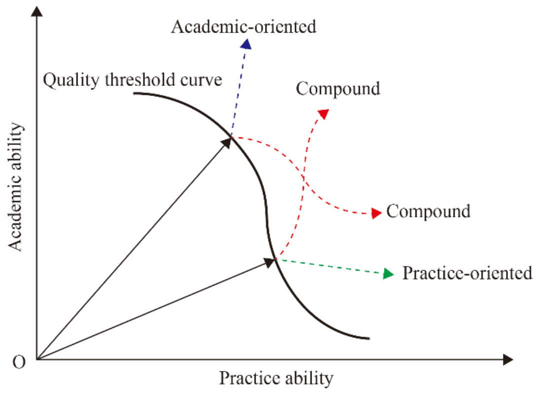

Fig. 1. Training path of engineering practitioners.

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4.3 Student assessment and evaluation: contradiction between explicit ability and hidden quality

The existing student assessment system in colleges and universities emphasizes students' explicit abilities, such as Grade Point Average and academic paper publication, but ignores their hidden qualities, such as social responsibility, international vision, cultural tolerance, and patriotism. Fundamentally, it has failed to truly foster virtue through education. Hidden quality is actually an important starting point to promote virtue-based education, and only when it is integrated into the whole process of engineering, science, and technology training, can we effectively achieve the basic goal of education, namely, promoting all-round human development. At present, the engineering education accreditation and graduation requirements in China are basically the same as the framework of the Washington Accord [20], covering 12 competences, such as engineering knowledge, problem analysis, and tool use. In contrast, most member countries have not completely followed the graduation requirements of the accord but carried out characteristic reforms based on their national conditions and educational practice. Likewise, the hidden qualities of Chinese traditional culture and Chinese socialist core values, such as harmony, tolerance, and patriotism, should be incorporated into the accreditation standards so as to establish an accreditation system with Chinese characteristics and equivalent international efficacy. Such a system can also further strengthen the implementation of virtue-based education in colleges and universities and thus achieve a balance between students' explicit abilities and their hidden qualities.

5 Strategies for implementing 2030 ESD in China

5.1 Strengthening top-level design to leverage policy synergy

Since *Agenda 21* set the blueprint for global sustainable development, the Chinese government has actively responded to it and carried out ESD-related practices. *China's Agenda 21* issued by the State Council in 1994, the world's first national-level sustainable development strategy, comprehensively expounded China's strategic goals and action plans for sustainable development in various fields, such as social and economic sustainable development. In particular, it emphasized the important role of education in achieving sustainable development. Since then, China has issued a series of successive policies on sustainable development, forming a relatively sound system. However, because few documents are specifically targeted at ESD, strengthening the top-level design becomes a pressing need in China. In terms of policy design, first, it is necessary to formulate ESD planning documents based on China's special conditions by referring to the basic concepts of the *Education 2030 Framework for Action* and promote the overall innovation and systematic design of ESD goals, content, and methods. Second, we should give full play to the policy synergy by effectively integrating and practicing China's existing ESD documents of different levels, types, and natures so as to achieve the "1+1>2" effect. Third, it is necessary to implement an ESD promotion project and design its roadmap and timetable from multiple perspectives, such as strategic coordination, social mobilization, resource input, curriculum development, supervision, and evaluation, which can effectively promote the realization of ESD goals.

5.2 Promoting international cooperation to integrate global high-quality resources

China has attached great importance to high-quality international cooperation and has gradually become a leader in advancing international sustainable development. In particular, China places a high value on the convergence of the Belt and Road Initiative and the UN 2030 Agenda for Sustainable Development, and it upholds the principles of extensive consultation, joint construction, and shared benefits when promoting the common development of countries along the Belt and Road [21]. To further deepen international cooperation and integrate high-quality resources for sustainable development, it is necessary to establish bilateral or multilateral cooperation centers, conduct international cooperation projects, and encourage open education. First, China should establish ESD bilateral or multilateral engineering cooperation or research and development (R&D) centers, integrate high-quality resources through school-running models, teacher training, textbook development, infrastructure, quality evaluation, etc., and develop high-quality engineering education to reduce poverty, protect the environment, promote gender equality, and achieve other SDGs. Second, it should carry out special international cooperation projects in engineering education; strengthen R&D cooperation and exchanges of teachers and students, with a focus on global hotspots, such as science and technology R&D, healthcare, and environmental protection; and jointly foster high-standard professionals in ESD. Lastly, it is necessary to encourage open schooling and guide Chinese universities to vigorously develop ESD through Sino–foreign cooperation in running schools and developing education for international students. In the context of the new Industrial Revolution, schools should formulate their own mid- and long-term ESD goals that are in line with the features, structures, and types of their engineering education.

5.3 Optimizing academic discipline structure to leverage specialty clusters

In response to the national strategic priorities, science and technology development, and industrial upgrading, it is necessary to establish an engineering education system that is oriented to the 2030 Agenda for Sustainable Development. First, education departments should conduct an in-depth investigation into the quantity, structure, and levels of engineering professionals needed by industrial enterprises and establish a complete forecasting system for related human resources to achieve a dynamic balance of talent supply and demand, while offering a scientific basis for the optimization of the engineering education structure. Second, it is necessary to transform the traditional architecture of academic disciplines and incorporate a dynamic adjustment mechanism guided by the concept of sustainable development, which means appropriately expanding the scale of majors that can meet national strategic needs and sustainable development, or else cutting them down gradually. Third, engineering education should balance the development between basic science and applied science, between uni-disciplinary and multi-disciplinary majors, and between traditional majors and emerging majors. More importantly, the integration of professional high-quality resources should be strengthened based on the frontiers of engineering technology and the needs of socioeconomic development, thus to form a cluster of multi-disciplinary engineering majors and achieve a coordinated development of different disciplines for ESD goals. Fourth, it is necessary to properly handle the relationship between the government, enterprises, society, and universities, and encourage multiple stakeholders to contribute efforts and wisdom to optimizing academic layout and serving regional and even global ESD. Overall, on the basis of an accurate forecasting system for engineering professionals, engineering education will be able to contribute to ESD goals more effectively through multi-party collaboration, improvement of the dynamic discipline adjustment mechanism, and establishment of strong specialty clusters with distinctive features and priorities.

5.4 Empowering teaching to develop outstanding engineers

ESD aims to motivate learners to become citizens committed to sustainable development, with independent judgment, critical thinking, and willingness to create a sustainable society in the future. Continuous innovation and reform of curriculum and teaching is an effective way to achieve this end. Three aspects are key to developing qualified engineering practitioners dedicated to sustainable development through engineering education: first, establishing a multi-level and three-dimensional curriculum framework with different orientations such as academic research, science popularization, or general knowledge, based on the varied features and needs of students, and, in particular, incorporating industry norms and engineering ethics into the curriculum design; second, embedding modern information technology into teaching, immersing the sustainable development concept into the emerging technologies like blockchain, AI, and learning science, and effectively monitoring teaching and learning states to build a learning environment that can continuously empower learners' personalities; third, forming a learner-centered teaching mode, so that students can actively explore the unknown instead of simply passively accepting information. At present, two typical mature teaching modes in global engineering education, namely, problem-based learning and case-based learning, are both student-centered methodologies, and we can learn from both and further develop them. Generally speaking, student-centered teaching modes encourage students to develop critical thinking and introspection, integrating the concept of sustainable development, which can contribute to the development of outstanding engineering professionals with patriotism, a high sense of responsibility, and commitment.

5.5 Improving accreditation and quality standards system

Professional accreditation, as the most important tool and means of quality assurance in engineering education, plays an important role in training objectives, designing curriculum, building a teaching team, etc. At present, the United Kingdom, the United States, and other developed countries have established a sound professional accreditation system, with related standards, procedures, and experts in place. In addition, since the cross-border flow of engineering professionals keeps increasing, some global or regional mutual recognition agreements have taken shape, such as the Washington Accord at the global level and the European Network for Accreditation of Engineering Education at the regional level. Currently, the graduate requirements for engineering education accreditation in China are basically consistent with the framework of IEA and have been continuously improved and revised to further reflect China's development characteristics and reality. In the future reform of professional accreditation standards, we should take virtue-based education as the guide, further embody the qualities of Chinese traditional culture and socialist core values, such as harmony, inclusiveness, and patriotism in the standards, integrate

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the sustainable development requirements, and ensure international substantive equivalence while keeping Chinese characteristics so as to further consolidate virtue-based education in colleges and universities.

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