Asia Pacific Education Review (2023) 24:145–165
https://doi.org/10.1007/s12564-022-09743-y

Developing a synergistic approach to engineering education: China's national policies on university–industry educational collaboration

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Received: 15 June 2021 / Revised: 24 December 2021 / Accepted: 25 January 2022 / Published online: 14 February 2022
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Abstract

This article examines the intents and effects of China's national policies to promote a synergistic approach to university–industry collaborative education. These policies set out to reduce the academia-industry disconnection for engineering education. Based on document analysis and interviews with various types of stakeholders, the study reveals that China has strived for a synergistic approach to education by strengthening the main-actor role of enterprises, framing a policy support system, incorporating external stakeholders in universities' governance structures, and building a coordinated framework for a synergistic approach to education. These policies have enhanced enterprises' motivation to participate in university education, deepened enterprises' engagement with engineering education at course level, and created an educational innovation ecosystem. Some challenges remain such as the mismatch between course update and technological development, the mismatch between costs and return for faculty members, and difficulty in assessment of outcomes. Overwhelmingly, China has tried exploring a model conducive to the improvement of higher education quality, and the overlapping triple helix model, compared with the statist or laissez-faire patterns, has a more robust effect in galvanizing stakeholders towards their collective goal in the Chinese context.

Keywords University–industry collaboration · Educational collaboration · Synergistic approach to education · Engineering education · Chinese higher education

Introduction

The academia-industry disconnection is a long-standing problem in higher education sectors across countries, especially in the engineering field (National Academy of Engineering, 2005). While the industry has witnessed the acceleration of technological innovations, university programs often rely on outdated knowledge misaligned with authentic engineering practices (Brunhaver et al., 2017; Graham, 2018). Authentic engineering projects typically involve plenty of 'complexity, ambiguity, and contradictions' (Johri & Olds, 2014, p. 121). In contrast, university engineering education is often characterized by knowable and well-structured solutions attainable only through the finite application of a set of rules and principles (Stevens et al., 2014). Moreover, most faculty members have little industry experience and knowledge of authentic representations of engineering work, such as the dispositions, skills, and identity orientations of professional engineers (National Academy of Engineering, 2005; Stevens et al., 2014). As a result, university students often have a vague understanding of what professional engineering work involves and are ill-prepared for professional engineering practices in authentic industry contexts, according to many employers (Lattuca et al., 2014).

Bringing in enterprises as education collaborators is viewed as an important means of improving university engineering education (Wardale & Lord, 2016). Compared with higher education institutions, enterprises carry more conviction in the mastery of the state-of-the-art technological development. In this Industry 4.0 era, establishing an all-out university–industry partnership constitutes an important mission for engineering-savvy universities of many countries, such as the US, the UK, Netherlands, Australia, and Singapore (Graham, 2018).

However, most current university–industry collaborations revolve around research (Ankrah & Al-Tabbaa, 2015;

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Etzkowitz & Zhou, 2017), with collaborative education or joint teaching practiced to a much lesser extent. The joint effort between enterprises and universities in co-developing practice-oriented engineering courses, assessment mechanisms, and praxis education schemes that are closely bound up with students' learning, remains in its infancy worldwide (Crawley et al., 2014; Graham, 2018).

Such weak collaborations derive from the innate conflicting goals and interests of enterprises and universities as different types of organizations (Crespo & Dridi, 2007). Research has shown that deep collaboration between organizations rests upon interlocking social, economic, and epistemological conditions, such as necessity, reciprocity, efficiency, stability, legitimacy, and asymmetry (Ankrah & AL-Tabbaa, 2015; Oliver, 1990). As such, it is crucial to address concerns, align their interests, and realize synergy for both enterprises and universities for an enduring university–industry educational collaboration.

Although a latecomer to scientific and technological forefronts, China has been striving to keep up with international engineering leaders to improve the country's overall competitiveness. In recent years, China has especially accentuated the need for a 'synergistic approach to education,' where enterprises and universities are effectively integrated and syncretic in cultivating science, technology, and engineering talents. Accordingly, a series of national policies on promoting university–industry collaborative education has been released. These policies themselves represent cross-departmental synergy, involving not only the Ministry of Education (MOE) as an educational authority, but also other prominent departments (e.g., The Ministry of Industry and Information, and the Chinese Academy of Engineering) and even the State Council, the highest administrative body in China. Furthermore, the policies provide substantive mechanisms to address complex factors hindering collaboration between stakeholders and are likely to have a systematic impact on China's higher education landscape.

This paper aims to examine China's latest national policies on guiding university–industry collaborative education, with a special focus on policy intents and policy effects on undergraduate engineering education. As the analysis conveys, multiple types of stakeholders, including the government, the enterprises, and higher education institutions, will loom large when it comes to the implementation of relevant policies for the ideal collaborative engineering education at university level. The stipulated rights and obligations of each type of stakeholder vary but are also inter-connected and complimentary in fueling changes of engineering education at various levels (e.g., course level, system level), entailing visible and invisible costs and gains for each party involved. Such tie-ups, however, have reduced, if not eliminated, the gap between engineering education on campus and engineering practices at workplaces. As such, two research questions underpin the present study: (1) What are the roles that the government, enterprises, and universities are supposed to play separately and collectively in developing the synergistic approach to engineering education according to China's relevant national policies? (2) What progress at course level and system level has been made for China's engineering education sector since the inception of these national policies? Considering the relatively sparse attention given to policies regarding university–industry collaboration in education in China—in contrast with collaboration in academic research—this study fills a research gap and adds to the global literature of higher education innovation.

Factors influencing university–industry educational collaboration

Enterprises and universities are organizations with distinctive properties and goals. Therefore, effective collaboration between them rests on pragmatic factors influencing inter-organizational relationships, such as necessity, reciprocity, efficiency, stability, asymmetry, and legitimacy (Oliver, 1990). Ankrah and Al-Tabbaa (2015) describe necessity as the extent to which the collaboration serves each side's development strategy, whereas reciprocity means both sides can substantively benefit from the collaboration. Harman and Sherwell (2002) maintain that efficiency encompasses whether universities can draw external funding resources from the collaboration with industry against the backdrop of shrinking governmental funding, and whether industries can access financial gains through commercializing university-based technological innovations, resulting in cost-saving and enhanced technology development capacity. Stability concerns the predictability of each party's contributions to the collaboration and the mutual dependability on each other to achieve common goals (Ankrah & AL-Tabbaa, 2015; Oliver, 1990). Asymmetry points to the comparative advantage that each side possesses to serve the other's interest and the advantage sought from the other side for their own gains, and legitimacy entails collaborators' demonstration of social responsibility in the pursuit of higher prestige (Siegel et al., 2003).

Given global reductions in public funding, universities may seek ties with powerful companies as an alternative channel for fundraising, R&D, and technology transfer (Harman & Sherwell, 2002). In turn, collaboration with prestigious universities can help enterprises access high-quality research infrastructure and resources. However, the role of the government as a coordinator and supporter between universities and enterprises is frequently highlighted. Hence, government policies providing economic compensation for all collaborators involved are widely called for (Sá, 2011; Vega-Jurado et al., 2008).

Theoretical background

Triple helix model

The Triple Helix Model (THM) conceptualizes the trilateral interaction between government, industry, and higher education in pursuing collective goals (Etzkowitz & Zhou, 2017; Lawler, 2011). With a key belief that economic growth rests upon a complex process of knowledge and technology generation that demands effective interplay of the three sectors, THM demonstrates a spiral network based on innovative re-combinations of actors' functions and their evolutionary interaction, with each actor assigned distinctive roles for mutual support.

Within THM, the government's responsibilities include issuing regulations, providing support, and charting the overall innovation direction based on a systematic understanding of public and private demands proposed by other stakeholders. Specific government roles may include "co-financing," "enabling," "informing," "organizing discourse," "moderating," and "command and control" (Gachie, 2020). The role of academia is generating knowledge and transferring it to the industry to boost regional economic growth, while gaining funding from the government and industry to strengthen the conduct of research (Cai & Liu, 2015). The process involves universities' effort in non-traditional secondary activities such as the capitalization of knowledge, patents, and other intellectual properties (Po et al., 2016). The business sector contributes to academia for transformative outcomes in terms of research, teaching, and other endeavors. Concurrently, industry enjoys resources associated with the research infrastructure from academia and supportive government policies (Gachie, 2020). THM avoids the weaknesses of two opposing patterns, namely the statist pattern where government fully controls both academia and industry and takes the lead in project development and resource allocation, and the laissez-faire pattern in which government, industry, and academia are independent of each other, and unable to form effective solidarity (Cai & Liu, 2015; Etzkowitz & Zhou, 2017; Po et al., 2016).

Synergistic approach to education

Derived from the word "synergy," which refers to the cooperation of multiple parts, a synergistic approach signifies that elements within or across systems advance simultaneously by contributing to each other's improvement for a win–win situation. This approach differs from a contingency paradigm where one's improvement is at the expense of another (Meirovich, 2006). Such an approach conceives of conflicting sides as complementary and interwoven rather than polarized and in competition, upholding that each individual element has an inherent value to be acknowledged (Tararina et al., 2015). Furthermore, synergy denotes a state where a combination of things produces an effect greater than the sum of its parts, afforded by the energy, positive feelings, and mood states generated through collaboration (Beutell & Gopalan, 2019). Unlike the simple addition of elements mixed together, synergy not only incorporates different elements that work together, but also implies "chemistry" to produce something unexpected and extra through the combination and form "a new dynamically stable pattern of behavior" (Rusk et al., 2018, p. 409).

Despite the lack of a unified definition, the synergistic approach to education refers to collaborative efforts from stakeholders for educational purposes through resource sharing, mutual enrichment, partnership establishment, responsibility co-undertaking, and advantage complementarity. It is a process where higher education institutions "borrow forces" from other sectors to improve teaching quality by offsetting their innate weaknesses. At the same time, business and R&D departments gain potential and long-term human power by offering training platforms, research facilities, and praxis bases to partner universities (Sun, 2020). It results from collaborative arrangements within an innovation ecosystem featured with shared knowledge and skills, common goals and objectives, and mutual dependencies for development (Nambisan & Baron, 2013).

The THM-based interactions for the synergistic approach to education in the Chinese context

In the Chinese context, China's attempts in the last five years can be encapsulated as striving for a synergistic approach to engineering education through THM-based interactions between the government, enterprises, and universities at both conceptual and practical levels. The tripartite interactions between the three parties have been carried out both conceptually and practically, with the essence of triple helix model manifest in such intensive interactions.

Conceptually, as early as 2017, China's top administrative body, the State Council, issued an overall guidance document on facilitating university–industry collaborative education, *Opinions on Deepening Industry-education Integration* ("*Opinions*" hereafter), which maintains that concerted effort must be made to form a landscape in the whole society where all parties work together for a synergistic approach to education at undergraduate level. Out of the recognition of the collective role in fueling educational innovation, the State Council especially asked for deepened interaction between various stakeholders to create favorable conditions for enterprises to engage deeply in course development and student development at higher education institutions (State Council, 2017). Before long, three important departments at national level, the Ministry of Education, the Ministry of Industry and Information, and the Chinese Academy of Engineering jointly issued a more detailed guideline on developing extraordinary engineers in 2018. This new guideline required that there must be legal and institutional mechanisms in place to ensure that the synergistic approach to education be implemented based on different stakeholders fulfilling their respective duties. Specifically, it explicated that Party Committees, government bodies, and their subordinated social organizations bear responsibility for improving recruitment mechanisms for student internships and authentic engineering praxis, evaluating and assessing a multiplicity of engineering praxis bases, deploying an array of effective platforms convenient for university–industry collaboration to take place, and guiding enterprises to assist and prompt university education to change at micro-level (e.g., course level). Enterprises are supposed to fund for collaborative programs and above all provide state-of-the-art technology components and industrial expertise to higher education institutions, while higher education institutions ought to draw upon all resources and opportunities available to expose their faculty and students to authentic industrial expertise (MOE, MII & CAE, 2018).

On a practical level, the tripartite interaction between the government, enterprises, and universities has been carried out mostly through seven stages in a regular manner. Every year from 2017 onwards, the three parties have had more interactions focusing on university–industry collaborative education than years before. The seven stages of interaction include but are not limited to notification release, symposiums and meetings, guideline submission, qualification review, selection of partnerships, collaboration implementation, supervision, and assessment of collaboration processes. These steps combined have instituted a system of formal interaction, identification, and mutual understanding of the real demands for education quality improvement on campus among all parties. The effort has largely resulted in an overall landscape at variance with the situation before 2017 where university–industry collaborative education had merely titular importance, no external forces outside campus understood the crux of university engineering education, and universities had few accesses to external education-facilitating opportunities and resources. The specific contents of the seven stages of tripartite interaction between the three parties will be detailed in the following "Findings" section.

This study

To analyze how the synergistic approach to education between enterprises and universities has been constructed and adopted in China, we draw on documentary analysis of various policy documents and semi-structured interviews with government functionary, enterprise project managers, faculty members in charge of collaborative projects and university administrative staff.

Documentary analysis enables understanding of social constructs and realities and reflects relevant adopted beliefs, especially when a policy being studied is relatively new (Liasidou, 2019). The method is considered "a useful research strategy for linking theory and practice in early years settings" (Davis, 2012, p. 275), and "an essential source of information concerning the reaction and perspectives of the government and various stakeholders as the main actors" (Liasidou, 2019, p. 77).

Our documentary analysis was geared towards identifying underlying and recurring themes concerning the latest university–industry educational collaboration, with a special focus on how such collaboration fuels educational innovation at universities, and the roles it requires government, universities, and the industry to separately and collectively fulfill. The inclusion criteria were that the documents should concern university–industry collaboration in education (rather than research or other aspects), and should be from 2017 onwards when the synergistic approach to education started to gain currency. A total of 17 official documents were identified for analysis, including

(1) One state council's released opinion;
(2) Six ministerial regulations and decisions;
(3) Five formal ministerial announcements; and
(4) Five batches of released synergistic education project profiles (Appendix).

We also carried out semi-structured interviews which offer an opportunity "for creating and capturing insights of a depth and level of focus rarely achieved through surveys, observational studies, or the majority of casual conversations" (Forsey, 2012, p. 364). A purposive sampling method with the advantages of locating information-rich cases (Patton, 2015) was used to identify participants. Specifically, the typical case sampling technique was employed as this method allows the researcher to study and compare a given phenomenon (e.g., collaboration) to the typical behaviors of the population of interest. Given the focus of this research being the tripartite interaction between the three types of stakeholders, representatives of the government, the industry sector, and the higher education sector are our population of interest. As such, we purposively sampled participants including government functionary responsible for nationwide synergistic education projects at MOE, company project managers in charge of the industry–university collaboration, university faculty members participating in collaborative projects with industry, and university staffs serving for educational collaboration (Table 1). Regarding the data collection techniques, the first author directly contacted

Table 1 Participating interviewees

Pseudonym	Type	Job content
Func-A	Ministry of Education functionary	Contact person at the department in charge of university–industry collaboration; responsible for resolving inquiries from enterprises regarding application standards and collaboration procedures, and organizing expert panels to review applicants' materials and qualifications
Com-A	Company project manager	Working with a laboratory teaching equipment-focused manufacturing company in Nanjing; responsible for market exploration, liaison with the government and universities on collaborative education requirements, and product advertising
Com-B	Company project manager	Working with a laboratory teaching equipment-focused manufacturing company in Nanjing; responsible for communicating with the university side on demands and service provision; having collaborative ties with around two dozen higher education institutions in China
Com-C	Company project manager	Working with a Chinese IT giant based in Hangzhou; responsible for establishing and maintaining service connection with universities that participate in university–industry education collaboration
Com-D	Company project manager	Working with a Chinese IT giant based in Beijing; responsible for communicating with university faculty members and principle investigators on the integration of company technology with students' course system
Com-E	Company project manager	Working with a Chinese IT company in Beijing; responsible for visualizing students' learning of engineering theoretical principles in textbooks by making use of VR and AR technology
Fac-A	University faculty member	Associate Professor, teaching telecommunication principles and theory and other related courses at an engineering-savvy university in Nanjing; in charge of a collaborative education project on developing a comprehensive experiment platform in collaboration with the hi-tech company Wuhan Easy Start
Fac-B	University faculty member	Professor, teaching numerous electronics engineering-related courses and having more than 10 years' experiences in guiding college students' academic contests at an engineering-savvy university in Nanjing; in charge of three collaborative education projects with leading foreign IT companies such as Texas Instrument, ARM and Renesas
Fac-C	University faculty member	Assistant Professor, teaching wireless communications at an engineering-savvy university in Beijing; in charge of a collaborative project on developing authentic praxis bases with a high-tech Shenzhen-based company
Fac-D	University faculty member	Assistant Professor, teaching material science at an engineering-savvy university in Beijing; in charge of a collaborative project on developing VR-supported teaching cases of mechanized equipment with an education technology company in Jinan
Fac-E	University faculty member	Associate Professor, teaching courses related to automobile engineering at an engineering-savvy university in Beijing; in charge of a collaborative education project on reforming the teaching of the course Machine Learning with the IT giant Baidu
Fac-F	University faculty member	Assistant Professor, teaching electronics engineering-related courses at an engineering-savvy university in Beijing; in charge of a collaborative education project on reforming the experiment part of the course Digital Circuit with an IT company in Beijing
Staf-A	University staff member	Deputy director of the Office of Teaching Affairs at a collaborative project-involved university in Nanjing
Staf-B	University staff member	Staff with the Office of Teaching Affairs at a collaborative project-involved university in Nanjing
Staf-C	University staff member	Section chief of the Office of Teaching Affairs at a collaborative project-involved university in Beijing
Staf-D	University staff member	Staff with the Office of Teaching Affairs at a collaborative project-involved university in Beijing

functionaries at MOE in request for the interviews. As some functionaries' job duties included issuing yearly notifications on the collaborative education, answering open questions from enterprises and universities regarding collaboration procedures and conditions, and resolving inquiries regarding application standards, and qualification reviews, they were fairly easily reached and open to receiving various types of inquiries, including interviews. Furthermore, as the authors have engineering backgrounds, we contacted two gatekeepers at two engineering-savvy universities in the cities of Nanjing and Beijing, respectively, relying on existing social networks. The gatekeepers themselves are faculty members in charge of an education project in collaboration with IT companies. Apart from receiving our interviews themselves, the two gatekeepers also recommended their collaborators in the company, and also several of their university colleagues, including both faculty members and administrative staff members, to receive our interviews. These colleagues further recommended their respective company partners as well. Finally, a total of 16 participants were interviewed upon consent, including one government functionary, five company project managers, six university faculty members, and four university staff members. Interviews were conducted between September 2020 and March 2021, each lasting approximately 45 min to one hour. Pseudonyms were used to protect participants and their affiliations for anonymity.

For both document and interview data, we followed an approach of constant comparison analysis in an inductive and recursive manner (Glaser & Strauss, 2017). We identified, compared, and contrasted thematic analysis of relevant policy documents and interview transcripts through repeated reading. Our initial coding scheme was developed based on research questions and theoretical frameworks. Sensitizing concepts, such as policy intents, supportive measures, stakeholder roles, and policy effects that were key focuses of the study guided the coding process (Patton, 2015). Recurring words, phrases, and statements concerning the research questions were located. Then an axial coding scheme was adopted to divide the above aspects into more detailed and meaningful categories through which the dimensions and relationships within and across these categories were identified. Not only perceptions but also procedures were given special attention during this phase of coding. Next, a thematic analysis was undertaken through which shared and underlying meanings regarding distinctive and common efforts for the synergistic approach to collaborative education were identified. Interview quotes were translated into English by the first author and double-checked by the second author. There were extensive discussions between authors regarding the codes, interview transcripts and translations. Codes from interview transcripts included most codes from policy documents, but additional codes were also covered beyond the policy texts, indicating that interviews were mostly consistent with policy intents, but provided more insights and details than policy documents per se.

Findings

Institutionalized tripartite interaction among the government, industry and university

The analysis of various selected policy documents reveals that compared with before, the tripartite government–industry–university interaction has been institutionalized formally on a regular biannual basis since 2017. Every phase of such interaction is carried out through seven stages.

In the first place, every year from 2017 onwards, MOE on behalf of the government issues opens notifications to call for enterprises to submit a guideline on their intended engagement in university–industry collaborative education. In such notifications, the government stipulates the main categories of potential collaborations between the enterprises and universities, the minimum qualifications for prospective participating enterprises, and how the government will assess the collaborations. MOE distinguishes six categories of projects for the industry and universities to collaborate (Table 2). Companies are allowed to collaborate with higher education institutions through some or all of the six categories. For each category, the government bears responsibility to mobilize human power and professional experts to form panels on the supervision of the implementation of collaborative education. It also sets the bar conditions that any participating enterprise must have no less than a registered capital of five million RMB with no recorded credibility problems over its business history (MOE, 2020).

Second, the government convenes biannual symposiums of enterprises and higher education institutions for mutual knowledge of potential collaboration opportunities. In such meetings, representatives from the three parties communicate with each other directly and openly over their questions, problems, concerns, interest pursuits, and other relevant issues in forging potential collaboration. Representatives of enterprises, not only those that have the most impact on the society but also have unique strengths in technology, research and development, and output transfer, are invited to showcase their products to all sides and introduce how their products can directly and indirectly facilitate improvement of higher education quality. University representatives are invited to share their demands as to which aspects of teaching and learning in what areas should be strengthened and what resources they are lacking to achieve their goals. There is free time for representatives of both the university side and the industry side to know one another (CEDU Media, 2020).

Third, enterprises write and submit dozens of guidelines to a special government platform on university–industry collaborative education and select the categories through which they intend to collaborate with prospective universities. The guidelines usually cover a broad range of issues

Table 2 Collaborative University–industry Education Project Categories

Category	Duties
1. 'New Engineering Education' overall development project	Enterprises provide funds and resources to help universities explore effective and evidenced implementations of innovative educational patterns in various engineering disciplines, such as collaborative education, synergistic education, and collaborative talent nurturing
2. Teaching content and course system reform project	Enterprises provide funds, expertise, technology and platforms to incorporate state-of-the-art technological advancement in industry into the university education process to fuel the upgrade of teaching contents, course structure, educational cases, and textbook content
3. Faculty development and training project	Enterprises provide resources to co-organize training activities with universities to improve faculty members' pedagogical skills, engineering experiences, and abilities related to teaching, praxis, and research
4. Praxis education and base development project	Enterprises provide funds, software, hardware, and platforms to support universities to develop laboratories, praxis education bases, and resources. Enterprises are also expected to recruit students for apprenticeship and internship
5. Innovation education and entrepreneurship education reform project	Enterprises provide expertise, software, hardware, and investment funds to support universities to strengthen educational systems on innovation education, entrepreneurship education, praxis training, makerspace, engineering project incubation, and relevant platform development
6. Collaborative entrepreneurship education funding project	Enterprises provide funds, mentors, and research projects to support university students' practice and experience of authentic startup and entrepreneurship experiences

Source MOE (2020)

pertaining to the companies themselves and how they can do their part to contribute to the prospective collaborative projects. In the guidelines, enterprises must articulate their main scope of business, strengths of business, intended means to support higher education (e.g., course update, faculty pedagogical training, praxis building), amount of funding for the collaboration, intended collaboration outcomes and relevant assessment methods. Companies also pose collaboration requirements for the universities with which they aim to collaborate. For instance, AliCloud, a subordinated company affiliated to the renowned Alibaba, engages in university–industry collaborative education mainly through Category I, II, and III (Table 2). According to its guidelines, through Category I and Category II, AliCloud prioritizes to collaborate with "Double World-class" universities recognized by the MOE,[1] institutions whose certain courses are selected as national-level excellent courses, and those who have collaboration history with AliCloud in the past. Through Category III, AliCloud puts a premium on collaborating with universities in less developed regions in China (e.g., those in the country's Northwest part), hoping to provide more training to the faculty of those less-ranked institutions.

Fourth, MOE forms special panels to scrutinize materials, profiles, and qualifications of applying enterprises. MOE decides whether an enterprise meets the necessary standards for being a participating enterprise, approves those that meet the standards, and rejects those that do not. With the review outcomes double checked, the government announces successful applying enterprises to the general public and sets-specific procedures for higher education institutions to apply and select potential partner companies.

Fifth, higher education institutions apply and select appropriate enterprises approved by the MOE on the same platform based on their specific demands for education quality improvement and their perceptions of the strengths and provision of relevant enterprises. Multiple rounds of communication, on-site observation, product assessment, demand confirmation, and service negotiations take place prior to having the formal signature of contracts between the industry side (i.e., enterprises) and the higher education side (i.e., universities) (MOE, 2020).

Sixth, universities and enterprises carry out substantive collaboration as prescribed for a period of time (i.e.,

[1] "Double world-class" project, also translated as "double first-class" project, refers to China's national plan to build numerous internationally top universities and disciplines by the mid-century. The plan is that for a certain number of comprehensive premium universities, they have been supported by the Ministry of Education in full swing to strive to become top institutions across the globe. These institutions are called "world-class universities." For some other higher education institutions that are not competent enough at an aggregate level but still have strong programs and disciplines, these institutions are especially supported to develop some of their disciplines to be internationally outstanding, and are called "universities with world-class disciplines." On September 2017, China announced 42 "world-class universities" and 95 "universities with world-class disciplines." Overwhelmingly, institutions with a "Double world-class" label are universities in good standing in China.

usually 2 years), while the government plays a supervising role. Such collaboration proceeds in a variety of forms in line with requirements of each category mentioned above, such as by co-organizing pedagogical training, developing textbook-based tailored simulation software, teaching and learning state-of-the-art technology, visualizing theoretical knowledge through displaying complex and ambivalent authentic engineering principles, and so on. The collaboration is also based upon the strengths of the participating enterprises. For instance, AliCloud capitalizes on its mastery of state-of-the-art technology (e.g., AI, cloud computation, net of things and coding development) to support applying universities to update course contents. According to AliCloud's guidelines, university courses that can benefit from the collaboration cover a wide range, from common courses (e.g., computer network and layered architecture), to specialization courses (e.g., data science and pattern recognition), and to the most forefront courses (e.g., big data processing, cloud computation), and so forth.

Seventh, the tripartite government–industry–university interaction is also manifest in the supervision and assessment of the collaboration processes. Enterprises and universities have to review the collaboration outcomes at the end of a collaboration period, with each side providing evidences of improvement in agreed respects, such as teaching and learning methods or updated teaching contents. The government plays a supervising role throughout the whole collaboration by reviewing enterprises' verification of the collaboration outcomes and encouraging higher education institutions to submit special reports on the collaboration details. Each part weighs up the possibility of future collaboration through assessing relevant collaboration achievements and problems (MOE, 2020).

Policy intents

Strengthening the main-actor role of enterprises

The document analysis revealed that in the national effort towards the synergistic education, enterprises have been given much ascendancy and positioned as main actors. The importance attached to enterprises is manifest in a large proportion of the state and ministerial policies, regulations, and announcements, highlighting enterprises' roles in assisting the reform and innovation of university education patterns. "Yin qi ru jiao" (meaning bringing in enterprises into campus to facilitate education quality) is the tone set across state and ministry-level documents.

In *Opinions* issued by China's State Council, enterprises are called to engage deeply in universities' program planning, textbook development, educational design, course development and praxis education. Enterprise-university joint establishment of industry-oriented schools and colleges, laboratories, innovation and praxis bases is encouraged with supportive policies such as tax reduction. A premium has been placed on well-resourced enterprises in taking the initiative to offer institutionalized and innovative internship and praxis education programs to university students, and to co-develop special training bases. Universities are encouraged to bring in enterprises through purchasing entrepreneurial services and commissioned management. In some well-resourced regions and provinces, even having partial ownership of vocational schools is allowed for enterprises that offer tremendous capital, technology, management expertise and other support to higher education institutions. For each category of collaboration as stipulated by MOE in previous sections, it is the enterprises that are given more expectations to assist higher education institutions scale greater heights.

As noted by some interviewees, enabling enterprises' main-actor role is prominent in that enterprises stand at the leading edge of technological development and can help university course instruction to scale greater heights.

> Compared with government and universities, enterprises understand state-of-the-art technology and industrial demands. We want them to educate and train students in class directly. (Func-A)

> Great companies' roles are indispensable. Although I have a solid foundation in theory, I do not know applications of theoretical knowledge in authentic engineering contexts as well as those working in companies. I'm glad they have people co-design and co-update some course content with me in the collaborative education project. (Fac-D)

Such a main-actor role is manifest in their detailed responsibilities. According to the aforementioned *'Notification',* participating enterprises have to release collaborative project guidelines to articulate their contributions to higher education quality improvement. Prior to establishing authentic collaborative ties with universities, enterprises are required to convince the government and universities of the value of their involvement. Their guidelines should be released to the public for evaluation in terms of the project size, collaboration goals, scaffolding resources, expected outcomes in talent cultivation and other feasibility-related aspects.

For instance, Ali Cloud Computing Co. Ltd. (ACCCL), a subsidiary corporation of Alibaba, will provide its own technical products and platform resources to develop collaborative courses with university programs. For each collaborative course, ACCCL's technology elements are set to account for at least 25% of the overall course content. Another example is the IT giant Baidu. Collaborative universities have access to Baidu's Apollo Technology for praxis education, and Baidu provides experimental guidance (e.g., experiment outlines, state-of-the-art technology, and smart network vehicle test areas) to support universities' online experiments and offline training. Baidu aims to co-build laboratories for artificial intelligence, big data, and cloud computing with universities and is willing to offer its deep-learning platform, scheduling software and authentic technical cases for the contextualization of education.

Framing a policy support system on the part of the government

Along with the role of enterprises, the State Council, the highest national administrative body, emphasizes the importance of governments putting in place systematic policy support at all levels. It requires that the State Development and Reform Commission, MOE, Ministry of Human Resources and Social Security, and other governmental bodies issue cluster policies to support an integrative and synergistic approach to education between education and business sector. There are three major categories of supportive policies to fuel university–industry collaborative education: compensation-oriented policies, incentive-oriented policies, and development-oriented policies.

Regarding compensation-oriented policies, the state-level *Opinions* explicitly requires that "fiscal and tax departments at all levels should carry out structural tax-reduction measures for enterprises that participate in deepened university–industry collaborative education" and "increase investment in university–industry praxis education bases" (State Council, 2017, p. 1). Lawful reward income obtained by faculty members out of university–industry collaborative education should not be included as part of the performance pay, which means a reduced tax burden for both individual faculty members and their affiliations. Enterprises also enjoy discounts and favorable prices in purchasing land if they intend to co-develop vocational schools or higher education institutions. This category of policy is supported by various government departments including Ministry of Finance, State Taxation Administration, Ministry of Land and Resources, State Development and Reform Commission and many provincial governments.

Incentive-oriented policies are mainly manifest in financial support. The *Opinion* maintains that validated university–industry collaborative education projects are entitled to high-level government-business investment funds and even international financing varieties. Financial institutions are encouraged to support industry-education integration projects in accordance with the principles of controllable risk and commercial sustainability. This is achieved by innovating service modes, developing diversified financing varieties, and providing supportive financial services that fit the needs of university–industry collaborative education. For example, insurance companies are guided to set special rates for modern apprenticeships jointly carried out by enterprises and universities. The Central Bank (People's Bank of China), China Banking Regulatory Commission, China Securities Regulatory Commission, China Insurance Regulatory Commission, State Development and Reform Commission and Ministry of Finance are required to work together to issue supportive policies and mechanisms (State Council, 2017).

Development-oriented policies are those that promote learning from international experiences. Favorable policies ensure Chinese institutions recruit high-caliber talent from abroad who understand the best practices of university–industry collaborations. Moreover, establishment of a cross-boundary network on educational innovation is formally supported, exemplified by the *Opinion* encouraging Chinese colleges and universities to establish ties with industries and companies from countries as part of the 'Belt & Road' Initiative (State Council, 2017).

Incorporating external stakeholders in university governance structures

Accompanying the recognition of the importance of enterprise participation is the perception that universities need to adjust their governance structures to allow enterprises to have more say as important stakeholders. Unlike boards of directors in western universities, the degree to which social stakeholders participate in Chinese university affairs is limited given its power landscape (Yang, 2020). However, recent documents on university–industry collaborative education specifically mention governance reform as an aspect to address. The *Opinion* calls for the establishment of the board system to allow enterprises and social organizations to participate in university affairs, aimed at fueling integrative cross-sectoral and cross-disciplinary education that better caters to industrial demands and authentic engineering practices. Enterprises and universities are required to arrange special groups or project managers to drive the educational collaboration and ensure compatibility between both sides. "Shuang chong zhu ti" (literally translated as "double subjects", meaning both enterprises and higher education institutions are main actors for collaborative education projects) and "shuang chong shen fen" (literally translated as "double identity", meaning that university students have identities of being both a student and an apprentice) are now underscored across documents and according to interviews.

Building a coordinated framework for a synergistic approach to education

Both document analysis and interviews reveal that "xie tong yu ren" (meaning a synergistic approach to education) is a buzzword. Despite divergent interests, China has been building a coordinated framework in which education for competent graduates becomes a common goal for multiple stakeholders. As reflected by the *Regulations on University–industry Collaborative Education Programs*, MOE is the macro-administration formulating policies and regulations, coordinating and supervising program operation and quality, mobilizing resources to establish counseling and guiding expert groups, and selecting and disseminating excellent collaboration outcomes. Provincial governments as lower-level government bodies also bear responsibilities to promote a synergistic approach to education, including formulating concrete province-wide implementation schemes, providing supportive resources, establishing partnerships, organizing guiding committees, and facilitating cross-sectoral exchanges and integration. Enterprises, as the main actors, are responsible for issuing collaboration guidelines, communicating with universities and colleges on content integration, cooperation procedures, project inquiry, project implementation, and project evaluation. Universities need to formulate detailed management rules, include enterprises as influencing actors, and examine collaborative project effectiveness. Synergy is emphasized in cultivation goals, graduate attributes, faculty members' competencies, resource allocation, and management and service.

Regarding support, MOE has developed a special nationwide online platform for the submission, evaluation, and dissemination of collaborative educational projects. It has also coordinated a state-level panel for the synergistic approach to education, comprising renowned university disciplinary scholars, enterprise professionals, and industry association experts. Members of the panel are important figures from both academia and industry including the Vice President of Harbin Institute of Technology, the Vice President of Xi'an University of Electronics Science and Technology, Head of the BG Talent Development Department of Huawei Technologies Co. Ltd., and the Vice Managing Director of Chinasoft International Limited. As some interviewees noted:

> I think the degree of synergy is now much higher than before. In my project, enterprise tutors discuss how their technology can be well integrated with students' textbook knowledge. We discussed that a lot and re-designed the course syllabus together. It's a salient progress compared with before. (Fac-A)

Overwhelmingly, assessment, supervision, certification, coordination, and funding are keywords related to government bodies' roles in forging the tripartite interactions. Industrial expertise, frontline praxis provision, and funding are the main labels attached to enterprises. Absorbing, learning, and cooperation are the roles expected to be played by higher education institutions in the tripartite relationship.

Policy effects

Enhanced motivation for enterprises to participate in university education

Since the issuing of the State Council's *'Opinion'* and other policy documents in 2017, greater motivation has been created among enterprises to participate in university education through various synergistic projects. For every biannual meeting convened by MOE, thousands of delegates from hundreds of universities and enterprises attend it for policy consultation, strength dissemination, mutual understanding, and exploration of cooperation possibilities (CEDU Media, 2018).

As can be seen from Table 3, before the State Council formally issued the *Opinion* in 2017, the scale of collaborative education between university and industry was much smaller. There were only dozens of enterprises providing support for higher education institutions. For example, for both half years in 2016, there were merely around 40 companies interested in such collaboration. At the beginning year, when MOE formally kicked off the university–industry collaborative education in 2017, the number doubled in the year's first phase, with 89 enterprises supporting 4,586 collaborative projects. Then such collaborations welled up quickly, with participating enterprises further doubled and collaborative projects tripled in the second phase in 2017. The next year 2018 witnessed a further round of doubling of participating enterprises and many more collaborative projects, and the momentum has been sustained since then up till now. In the original words of a public official from MOE when he compared the year 2018 with 2011 in terms of university–industry collaborative education in China, "the number of participating enterprises has increased by 87 times, collaborative projects 121 times, and the involved total amount of funding 500 times" (People's Network, 2018).

These collaborative projects cover a broad range of state-of-the-art technologies, emerging industries and leading-edge technological developments, such as artificial intelligence, big data computing, precision medicine, intelligent healthcare, and smart unmanned aerial vehicle technology. According to an interviewee from MOE, enterprise applications for the collaborative education projects far exceeded the above number. MOE scrutinized enterprises' profiles and rejected applicants not meeting the required standards. For instance, a qualified enterprise must have a registered capital of five million RMB (approximately 770,000 US dollars) at least with no record of credit problems and have a recognized technical background (e.g., R&D capability, reputation for technological advancement). For each phase of collaboration, notwithstanding entitlement to certain favored policies, enterprises should provide at least 500 thousand RMB for all the collaborative projects they get involved. Applications from enterprises far exceeded those that were ultimately approved, indicating a strong inclination to establish ties with universities for collaborative education.

> Overwhelmingly, only around 50% to 60% of applying enterprises would be approved. They are active indeed. (Func-A)

As a matter of fact, on top of meeting the minimum qualification standard with a registered capital of 5 million RMB as stipulated by MOE, which seems not difficult for a plethora of enterprises, the scale of the companies and the attributes of the universities vary to a large extent. Companies involved in the university–industry collaborative projects can be those international and Chinese IT giants with global influence such as Google, Microsoft, IBM, Baidu, Huawei, Alibaba, and Tecent, as well as many more less-famous but still powerful companies with registered capital and revenues far outstripping MOE's minimum standards. Despite the fact that each company has a different budget plan as to the proportion of R&D funds in its total operations, they all seem to have taken an active position to respond to MOE's call for the collaboration with universities as a strategy to boost their own reputation and yield long-term returns. The industries that these participating companies cover encompass a wide range of sectors in the engineering area, from traditional fields (e.g., mechanical engineering, material engineering, electronics engineering, software engineering) to emerging ones (e.g., AI technology, big data computation, unmanned driving).

The tremendous variation of the attributes applies to higher education institutions involved as well. Participating institutions include those striving for world-class universities, such as Tsinghua University, Peking University, Zhejiang University, and other middle-ranking universities and even more lesser-ranked colleges which are much in need of improvement in teaching and learning.

In the meantime, it must be noted that although traditionally famous companies tended to choose to collaborate with renowned universities, this study has pointed out that the boundaries in terms selecting what tiers of partners are not fixed in this round of university–industry collaboration. For instance, in 2020, the illustrious IT giant Baidu collaborates with all tiers of higher education institutions, including top-tier ones (e.g., Shanghai Jiaotong University, Xiamen University, Beijing University of Aeronautics and Astronautics), middle-tier ones (e.g., Hunan University, Chongqing University, Southwest University) and more lesser-ranked ones (e.g., Jingdezhen Ceramic University, Honghe College, Zhejiang Institute of Media, and Communications). The same broadness of selecting partners also applies to other leading enterprises and universities. For instance, University of Science and Technology Beijing, an ordinary engineering-featured institution, has collaborations with both renowned companies, such as Huawei, Tongfang Knowledge Network Technology, and lesser-known companies like Zhejiang Tianhuang Science & Technology Industrial.

At an aggregate level, this round of university–industry collaboration establishment since 2017 in China is open to all the general public in its entirety.[2]

Enterprises' deeper engagement with engineering education at course level

Another finding was that the collaborative education policies facilitated enterprise engagement with university education not only at discourse level but substantively at course level. Based on ongoing communication between faculty members and project managers, participating enterprises incorporated plenty of "cold textbook knowledge" (Fac-C) into software underpinned by learner-friendly technology (e.g., animation and VR). In this manner, a plethora of complex, ambiguous, and elusive mathematics and engineering axioms, fundamentals, and theories were visualized and contextualized for better understanding.

Com-B and Fac-C shared an example of innovation in teaching pulse code modulation (PCM) in the course "Principles of Communications." They described the process of converting an analog signal into digital form, involving sampling, quantizing, encoding, and other sub-steps. Traditionally, instructors would teach definitions in the module, describe the three steps of the process, and show graphs for each main step, using words and static illustrations. Students would be taught by both instructors and textbooks that the analog message signal is first sampled, and then the sample amplitude is approximated to the nearest set of quantization level to generate a discrete signal, then converted into its binary form and decoded at the receiver to get the original message. Such a process, however, remains unclear to many students because the technical steps do not have direct mappings onto daily life, hence, superficial understanding. With collaborative enterprises, students would be able to watch, feel, and even try the process in a visualized, experiential and dynamic way. With relevant disciplinary knowledge incorporated into learning-facilitating animation software,

[2] Although it is impossible to list all the participating company and university names in this paper due to their enormity in quantity, international readers can get access to the lists through links shown in Appendix with the help of an online translator.

Table 3 Number of participating enterprises and collaborative projects from 2016 to 2020

Year	Phase	No. of participating enterprises	No. of collaborative projects	Source
2016	1	33	Unknown	http://www.moe.gov.cn/s78/A08/tongzhi/201605/t20160525_246129.html
	2	41	1518	http://www.moe.gov.cn/s78/A08/tongzhi/201610/t20161026_286196.html
2017	1	89	4586	http://www.moe.gov.cn/s78/A08/tongzhi/201704/t20170419_302868.html
	2	192	11,491	http://www.moe.gov.cn/s78/A08/tongzhi/201709/t20170930_315856.html
2018	1	346	14,576	http://www.moe.gov.cn/s78/A08/tongzhi/201805/t20180503_334906.html
	2	374	16,151	http://www.moe.gov.cn/s78/A08/tongzhi/201812/t20181214_363592.html
2019	1	324	10,647	http://www.huhst.edu.cn/cxyzx/info/1027/1778.htm
	2	346	12,350	http://yyxy.hznu.edu.cn/c/2019-12-03/2309878.shtml
2020	1	333	12,201	http://www.moe.gov.cn/s78/A08/tongzhi/202010/t20201015_494734.html
	2	366	13,621	http://www.moe.gov.cn/s78/A08/tongzhi/202012/t20201224_507448.html

students would be able to perceive all relevant steps, such as the original analog signal (in the form of a sinusoid), the work of sampling pulses (pulses frequently launched towards the sinusoid), the acquisition of the level value through rounding off (representing a discrete digital signal of different amplitude), and the decoding process (the conversion of digital signal back to the sinusoid at the receiver). Students would even be allowed to set parameters of their own choosing to visually observe contrasting effects.

Apart from developing teaching-facilitating animation and software, some enterprises also co-developed with faculty members new fundamental courses more closely related to authentic engineering practices in the industry sector. For instance, Com-D said that "Principles of Communications" was too basic for electronics-major students, offering only fragmented, bottom-level and unconnected principles fairly irrelevant to authentic product operations and development. They then co-developed another fundamental course, *Software Radio*, with the collaborative university to update the course.

Being it knowledge visualization or course development, it demands a great deal of ongoing communication between enterprises technicians and faculty members. Significant time is needed for a product to mature that consider both students' learning reality and industrial technological advancement.

> At the outset of collaboration, enterprises did n't know our students' academic level or our course contents. They improved their products step by step based on our extensive discussions. It is nearly two years now since the beginning. They are engaging deeply at the course level now. (Fac-B)

> We cast helping upgrade university instruction and course quality as an important business goal. This is the right direction for business as it facilities education quality. (Com-A)

Emergence of an educational innovation ecosystem

Apart from increased motivation and deeper engagement of individual enterprises, the policies have also triggered the emergence of an educational innovation ecosystem, with various stakeholders providing extensive intellectual, financial, technical, and professional contributions to engineering students' learning, based on function complementarity, resource sharing, and close communication. New patterns of engineering education—as opposed to traditional lecture-based instructor-centered models—have sprung up.

For instance, an upsurge of engineering student contests at national, provincial, and institutional levels has been triggered to fuel students' comprehensive engineering competence. The National Undergraduate Electronics Design Contest, co-organized by MOE and Ministry of Industry and Information, is now held every year under the auspices of leading semiconductor developers such as Renesas Electronics Corporation and Texas Instruments. These contests are design, project, and comprehensiveness-oriented, testing participants' conception, design, operation, analysis, and communication abilities. The preparation of these contests demands academic and industrial experts to develop application-oriented questions. Therefore, students preparing for these contests learn beyond their textbooks in terms of breadth and depth. Industry has played an extremely prominent role of providing training, setting up contest topics, developing questions, delivering professional guidance, and evaluating contest outcomes. According to our interviewee Fac-E, his student teams won a prize in the 2020 national contest, of which Texas Instruments' robot learning system suite was a key facilitator. The device helped students to apply a cluster of knowledge modules, including analog and digital signal conversion, motor drives, programming language, data structure, and algorithms. Hence, a deeper understanding of components and working principles of electronic system design was facilitated.

According to China's Higher Education Association, a total of 57 categories of undergraduate student contests have emerged, with hundreds of universities and colleges taking part every year. Tens of thousands of training resources (videos, lectures, question banks, etc.) produced by renowned scientists, academics, and engineers are openly shared with engineering undergraduates nationwide, regardless of institutions' stratified positions and resource constraints. As such, an ecosystem is provided where student learning is more open and no longer confined to textbooks, classrooms, and "cold knowledge" (Fac-C).

> I don't dare say the synergistic education is perfect, but an innovation ecosystem, not necessarily for technological innovation, but definitely for educational innovation, has emerged. Even ten years ago, far fewer students had access to company resources. Much progress indeed. (Staf-A)

The national policies have given rise to amplifying effects within China's governance system, mobilizing all lower-level governmental bodies to catalyze the synergistic approach together. It is worth noting that while there exist decentralized elements indeed, which means that many top-level policies have to be implemented by lower-level government bodies and organizations, the lower-level implementers have to align their actions with the policy goals of the central government. Local bodies are granted the rights to pursue excellence and innovation, but only in terms of means and methods rather than goals and objects. It is crucial that provincial and local governments evaluate performance against centrally set targets as their way of operating in the system (Biddulph, 2018). As such, when MOE on behalf of the central government for the education sector launched the university–industry collaborative education project in the spirit of State Council's guiding document, local governments translated MOE's ideas onto their administrative agendas.

Jilin province in Northeastern part of China, for example, issued its special policy on promoting the synergistic approach to education in 2018 (Jilin Provincial Government, 2018). In the policy, Jilin provincial government also mentioned the intention to strengthen province-wide university–industry collaborative education through supportive tax reduction and financial leverages. The provincial Department of Education, Department of Human Resources and Social Security, Development and Reform Commission, Department of Industry and Information Technology, Department of Finance were asked to make joint efforts for the same goal (Jilin Provincial Government, 2018). Along with these policies, the provincial government, with the help of relevant industry associations, also built platforms for enterprises and universities for mutual understanding and project applications (Northeast Normal University, 2020). Since 2017, dozens of enterprises have established collaborative education ties with universities and colleges in Jilin over 2,000 plus projects (EDJP, 2019). Similar measures have been going on at local level in other parts of China as well, such as Zhejiang Province (Jinhua Polytechnic, 2020).

Activated benefit flows behind the synergy

To underpin the realization of synergy and the educational innovation ecosystem, our study identified some important benefit flows apart from the tax reduction for enterprises mentioned above.

When asked what sustains the ongoing engagement of enterprises with universities, our interviewees noted that enterprises were by no means mere contributors. Rather, they gained tremendous benefits in many forms during the collaboration. Although enterprises are required by the government to provide a certain level of funding and support platforms for the six categories of collaborative projects, collaborative universities would usually have to purchase many product sets from the enterprise for lasting use. Hence direct economic capital is paid to enterprises. Some enterprises offer their facilities for free to a proportion of their collaborating universities, typically premier institutions nationally or worldwide, in exchange for branding and public recognition. Once their products become well known in the domain, they target many more lower-ranked education institutions to sell products. Years of ongoing discussion with faculty members to ensure their software considers both students' learning reality and industrial advancement is a low-cost upgrade process, which enables their products to perform competitively in the market in the long run (Com-E; Fac-F). The courses co-designed and co-developed by universities and enterprises also promote enterprises in terms of their educational contributions and strengths. These enterprises attract more attention from the government and other universities and colleges for potential investment and purchases, ultimately resulting in more current and potential income. Moreover, enterprises can also jointly apply for patents provided that their collaboration yields innovative products with partner universities.

For higher education institutions, successful collaboration with enterprises is conceived of as innovation in educational patterns valued by society and government. The collaboration may also be regarded as reforming teaching methods and enhancing pedagogical skills required in national initiatives for engineering education development and expected by the general public. Institutions following the synergistic approach to education are entitled to more resources for institutional development, such as further governmental appropriations in reward for their reform efforts, greater social reputation for better instructional practices, and increasing donations and investments from society. The more prestigious and institution, the less it has to pay when collaborating with enterprises due to halo effects (Fac-F; Com-C).

The government supports both universities and enterprises in direct and indirect ways in exchange for better university education and higher caliber engineering graduates. In the short term, it benefits from completing various planned educational initiatives (e.g., New Engineering Education) within a given period (e.g., a 5-year plan period). The long-term benefits include upgraded economic development patterns, technology-based solutions to social problems and overall national competitiveness.

The benefit flow among the three types of stakeholders is shown in Fig. 1.

The benefit flows or the "cash flows" in the words of Staf-B are perceived worthwhile in that it is such flows that underpin the establishment of the collaborative education ecosystem. But for such transaction costs that flow from one party to another among the three, collaboration would have been only of titular importance, as before when there was no such formal mechanism to fuel the ties among these different stakeholders for educational purposes.

> To put it simple, collaboration needs money. Now with money or the cash flows in place, every side is incentivized to work for the same goal. Years ago, everything went no further than slogan. I could say this is really unprecedented in China's higher education history. (Staf-B)

The win–win social impact at educational and industrial sectors

The full impact of the university–industry educational collaboration is manifest beyond the education context, despite the defining impact that it has on higher education. Within the higher education system, profound changes have taken place in terms of education deliverers and education contents. Universities, as a matter of fact, no longer constitute the whole of higher education deliverer under the current synergistic approach framework. Various levels of enterprises, including world's top-500 have joined the educational initiatives in full swing and provided the university engineering education with new impetus. According to an internal publication by China's MOE, between 2015 and 2010, sixteen world's top-500 companies established a total of 2546 collaborative projects, with Google topping the list and initiating 721 such projects. Thirteen national top-500 companies participated in a total of 1317 such projects, with Huawei topping the list and supporting 387 such projects (Table 4). The industries where all the participating industries operate have covered a wide range of areas, such as tele-communications, software, information service, manufacturing, scientific R&D, agriculture, architecture, power business, transportation, hydraulic engineering, environment engineering, mining industry, and so forth (Shi et al., 2022).

More importantly, the contents of higher education have been empowered by the state-of-the-art technology from the industry. Traditionally, higher education institutions experience difficulties regarding faculty professionalism in the industry and timely updated contents in the course system. With university–industry educational collaboration in place, knowledge points broken away from key technological forefronts can be integrated in the university curricula. For instance, AliCloud has helped integrate the distributed architecture of cloud computation into the core courses for a variety of engineering programs (e.g., computer engineering, software engineering) to replace the traditional course string centered on single-chip-microcomputer fundamentals and applications. Enterprises have helped university courses to scale greater heights in praxis resources, easiness in use, knowledge contextualization, and customization in content delivery based on institutional needs.

Unlike the traditional landscape where only top-tier or key universities attract industrial partners for collaboration in China, the current round of university–industry educational collaboration has benefited institutions of higher learning at all levels. Among the top twenty institutions that have established the most collaborative projects with industrial partners, fifteen of them are ordinary institutions and only five are top institutions listed in the MOE's "Double World-class Project" (Table 5). Such a landscape indicates that ordinary institutions have become the backbone of the educational collaboration, thus, alleviating the long-standing quality stratification among Chinese universities and colleges. Moreover, the universities and colleges benefiting from such collaboration are not geographically confined to the most developed east and southeast regions of the country, but spread across China (Shi et al., 2022).

For enterprises, there are at least two types of benefits that can be obtained through injecting industrial elements into the university course system. The first aspect is that they can more readily recruit university graduates, especially from the collaborating institutions, who are kept abreast of the technical demands, authentic engineering settings, and the working milieu in the companies. Those who have received the companies' products' training are usually found to better cater to the requirements at the workplace and are more successful at early career stages. The second aspect lies in the activation of an industrial chain where helping universities with course improvement becomes a strategic formal business model rather than a bypass of enterprises' development. This means that a stable partnership has been secured for higher education institutions in terms of getting access to more innovative pedagogical practices and for businesses in terms of revenues from helping higher education institutions, hence, a win–win situation. Such a situation is also desirable

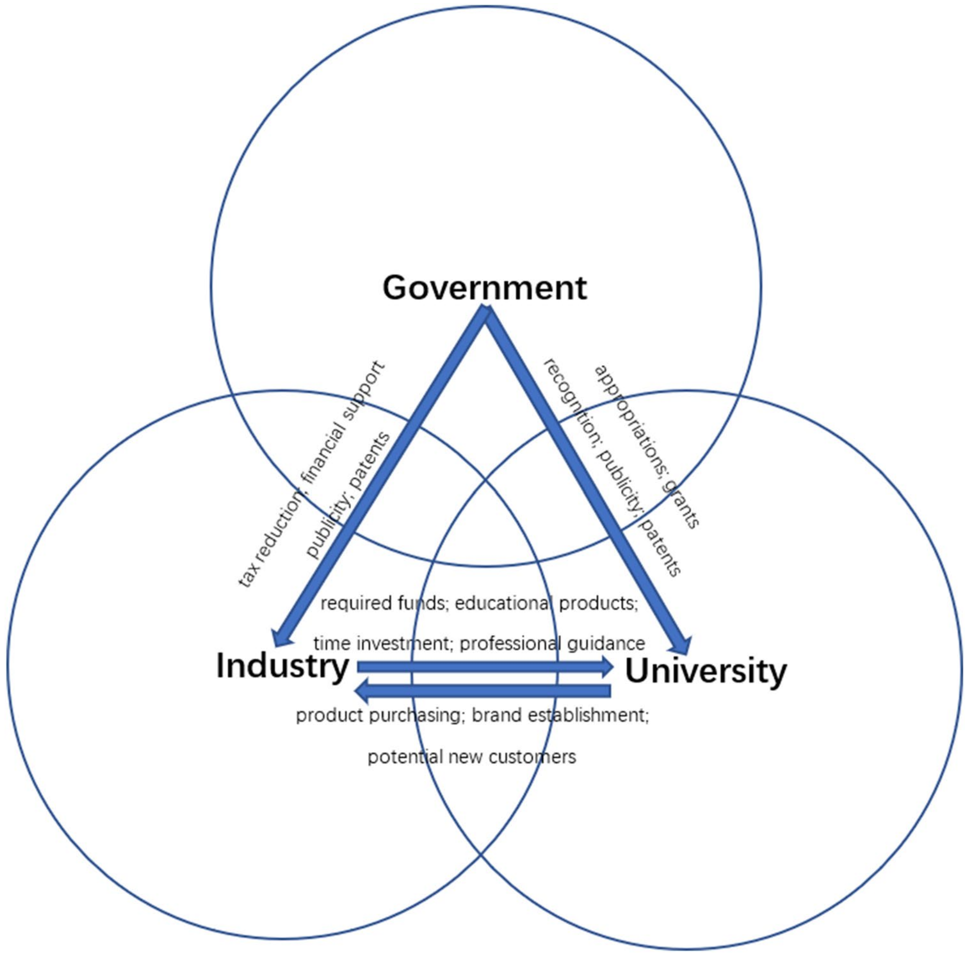

Fig. 1 "Benefit flow" among the government, enterprises, and universities

on the part of the government who has the responsibility to improve the overall innovation capacity.

Challenges

Despite conspicuous progress in the strengthened ties between university and industry as well as the positive impact of government policies in coordinating the collaboration compared with before, a few challenges must be noted pertaining to the incompatibility between the created external institutional environment and the remaining internal microcultures. Several existing structural barriers on the part of higher education institutions need to be further addressed.

Mismatch between course update on campus and technological advancement in the industry

Focusing on the industry has been the main theme of developing a synergistic approach to engineering education, and China's aspiration to update its university course system to cater to industrial demand has been salient. This is substantiated by the country's national New Engineering Education initiative which is Category I of the overall university–industry collaboration plans (Table 2). In fact, an essential part of the "new elements" of New Engineering Education is to establish new programs or develop new courses that fully cater to technological advancement in the industry (Zhuang & Xu, 2018). However, our interviews with faculty members who are in charge of the collaborative projects indicate that it seems to be a tall order for the university curricular system to catch up with the industrial progress in time. For many emerging industries and sectors, they do not have direct corresponding courses within higher education.

> Advancement in technological progress in the industry always proceeds at a greater rate than what university courses can change. The educational patterns may change from lecture-based instruction to project-based cooperative learning, but the degree of integration of industrial expertise with the curricular system is always limited in a sense. (Fac-B)

Table 4 Number of World's Top-500 and National Top-500 Companies Participating in the University–industry Educational Collaboration between 2015 and 2020

World's top-500		National top-500	
Google (China)	721	Huawei	387
Huawei	387	Baidu	324
Baidu	324	Tencent	311
Tencent	311	AliCloud	127
AliCloud	127	Shandong Jingbo	98
Microsoft Research Asia	127	Dahan Holding	21
Intel (China)	126	Xiamen C&D Corporation	19
Apple Inc	122	Lenovo	7
Amazon	120	Haier Group	6
IBM	102	Weiqiao Textile	5
Dell	49	Shaanxi Automobile	5
Schneider Electric	8	Jingdong Group	4
Lenovo	7	Beijing Energy	3
Haier Group	6	–	–
Weiqiao Textile	5	–	–
Jingdong Group	4	–	–
Total	2546	Total	1317

Source Shi et al. (2022)

Furthermore, while institutional leaders and faculty members have stronger awareness to introduce industrial elements into the course structure than ever before, the curricular modes or spaces that can be adjusted within most institutions' current system remain limited. For instance, according to Fac-A at a university in Nanjing, for a course she taught that has 64 h for theoretical teaching and 18 h for experimental teaching, it is only the 18-h experimental section that can be integrated with industrial elements. Such a limited proportion of experimental courses leaves herself and her enterprise counterparts limited autonomy to carry out integrated education. The similar situation is noted by Fac-C and Fac-F at another university in Beijing as well.

Incompatibility between cost and returns for faculty members as collaborative education implementers

Prior to the start of the collaborative education, Chinese faculty members were mostly undertaking teaching, research, and social service in their daily work but were already generally overwhelmed under the managerialism-based performance evaluation system (Huang & Xu, 2020). Now with the collaborative ties established with the industry, faculty members have to invest tremendous extra temporal and energy resources in extensive communication with their enterprise counterparts and adaptation to new knowledge from the industry. However, such extra effort remains seldom recognized in their career promotion system where academic research outputs and acquisition of grants still constitute the central position. As such, the cost and effort for the collaborative education projects have not brought them proportional payoffs yet despite their intrinsic recognition of the importance of collaborative education to students' competence growth, hence, the compromise in enthusiasm for lasting collaborative education.

> It is absolutely strenuous work to communicate with the enterprises on how their products can maximize their effectiveness by considering students' learning reality and zone of proximal development. For my own experiences, it took two years' ongoing communication for a collaboration to get mature, with both sides understanding subtle needs of each other. But apart from some economic compensation, such work is not counted much for our career promotion. (Fac-B)

Difficulty in assessing collaboration outcome for the government

Currently according to MOE's regulations, due to the ultimate purpose of facilitating university education quality through enterprises' assistance, participating enterprises are responsible for assessing whether the university side has successfully integrated industrial expertise with the course system. It is mostly at the discretion of enterprises to judge whether teaching contents have been updated or teaching and learning patterns have been innovated by their university counterparts. When company project managers verify a collaborative project with "pass" or "not pass," the government will further review the assessment results, both for the purpose of check and balance and for the selection of outstanding cases to further disseminate.

However, with hundreds of enterprises starting to support tens of thousands of collaborative projects every year, the pressure on substantively assessing the quality of collaboration for each project remains huge for the government, which undertakes the role of supervisor in the tripartite interaction. The main criteria now for government assessment come from self-reports submitted by enterprises. Although higher education institutions are encouraged to submit special reports on the details of the total collaboration process, the enormity of total number of projects poses huge pressure for the government as the third-party external assessors and supervisors.

Discussion

This study presented China's national policies that promoted the synergistic approach to university–industry educational collaboration, the overall tripartite interaction, and relevant

Table 5 Top-20 Institutions Having Established Most Educational Collaborative Projects with Enterprises in China between 2015 and 2020

No	Institution	No. of collaborative projects with enterprises
1	Shandong University of Science and Technology	603
2	Weifang Institute	476
3	Qingdao University of Science and Technology	470
4	Qingdao University	428
5	Lanzhou University of Technology	422
6	Chongqing College of Arts	397
7	Shandong University of Technology	391
8	Binzhou College	371
9	Dezhou College	368
10	University of Electronic Science and Technology of China[a]	356
11	Weifang University of Science and Technology	349
12	Qilu University of Technology	340
13	Dalian Minzu University	322
14	Hubei University of Technology	321
15	Xi'an Jiaotong University[a]	318
16	Dalian University of Technology[a]	316
17	Harbin Institute of Technology[a]	307
18	Shandong Normal University	304
19	Jinan University	282
20	Changshu Institute of Technology	282

Source Shi et al. (2022)

[a]Indicates key universities in China

the policy effects. The analysis contributes to the global literature on higher education innovation by uncovering the value of the synergistic approach to engineering education, its manifestations, and the mechanism which underpins such synergy.

The value of a synergistic approach for bridging engineering education and practice

Engineering subjects involve a preponderance of intangible and less visible concepts, high-order mathematics, and a high degree of abstraction (Johri & Olds, 2014). Abstract concepts and rigorous diagrams without concomitant practical and contextual demonstrations are cognitively unacceptable to most students (Godfrey et al., 2014). Thus, students need to contextualize abstract knowledge and understand authentic engineering practices for effective learning.

Against such a disciplinary backdrop, this study substantiates the importance of university–industry collaboration in bridging the gaps between engineering practices and engineering education (Crawley et al., 2014; Graham, 2018). As our data revealed, some companies co-developed *Software Radio* to replace the existing "Principles of Communications" as the fundamental course in light of their perceptions of what would be closer to engineering practices. Other companies developed animation and provided integrated experimental devices to help students visualize ambiguous engineering principles to facilitate their understanding of engineering knowledge. Other versatile measures included enterprises offering tutoring, resources, and expertise to improve engineering experiences of both students and instructors. Such a synergistic approach leverages the strengths of both sides as complementary forces to maximize student learning.

The findings also revealed that an integrated education pattern must be implemented at course level where students' active and experiential learning is unleashed. In this manner, the synergy and collaboration offset universities' innate weakness of being distant from the industry forefront, and directed industries to contribute to the quality of their potential future manpower by bridging the academia–industry gap. Such synergistic and collaborative approaches yield additional positive outcomes (e.g.. the innovation ecosystem) unachievable by any individual part, and support the concept of synergy that the whole is greater than the sum of its parts (Meirovich, 2006; Rusk et al., 2018).

Minimizing the academia–industry gap through the education-focused synergy

Unlike traditional academia–industry collaboration where research, patent, and technology transfer constitute the main aspects of collaboration (Ankrah & AL-Tabbaa, 2015; Harman & Sherwell, 2002), this round of university–industry collaboration in China has been fully education focused, and all the effort of building synergy is oriented towards improving university course update and minimizing the gap between what is taught in the academia and what is needed in the industry. The incentive policies by the government have enabled a large number of enterprises close to industrial forefronts to take on updating university courses and teaching methods as a formal business goal and an important development strategy. Contrasting with a decade ago when few companies would show interest in what was happening in the university system due to a sense of non-relevance and the lack of profit return, there is now a totally different landscape where company managers and university faculty and staff are inextricably related to each other discussing best practices and needed facilities in maximizing students' learning. Through such collaboration, far more students than before have got access to better teaching quality, hands-on practices, project-based training, and virtual simulation through customized teaching facility suites developed by enterprises in combination with the guidance of faculty members. As such, students have managed to develop more fully application skills based on more thorough understanding of what is needed in the industrial sector and more direct exposure to enterprise' provision of both hardware and manpower resources.

The effectiveness of an overlapping triple helix model for synergy in the Chinese context

This study notes that synergy does not happen automatically but is afforded by the cooperation, advancement, and mutual support of different parts geared towards a collective goal and win–win outcome. Coordination, incentive measures, and supportive policies are preconditions for achieving a stable pattern of synergy based on advantage complementarity and mutual enrichment. In our case, government, universities, and enterprises have all gained benefits serving their development strategies during the collaboration, congruent with the claim that synergy occurs when different elements interact in ways that reinforce each other to stabilize changes (Rusk et al., 2018).

In contrast with some studies arguing that university–industry collaboration is of no interest to Chinese companies due to insufficient room for profit gains (Po et al., 2016), our findings have revealed a vastly different picture, with enterprises having great enthusiasm for collaborative education. The rationale is that the THM guides the government, enterprises, and universities towards a mutually supportive relationship that caters to each side's costs and benefits. In contrast with the popular western stereotype that the Chinese government controls everything in a paternalistic manner using only administrative orders, it issues cluster incentive policies with substantive support to inspire collaboration between the different sides instead, fulfilling the function of co-financing, enabling, informing, and organizing discourse (Gachie, 2020). These policies have activated a broad range of potential benefit flows across stakeholders that cater to both short-term visible gains and long-term interests, with none feeling forced to make sacrifices during the collaboration. As such, enterprises are highly motivated, and the collaboration yields transformative outcomes at a course level.

The description of the interplay between government, industry, and higher education in the Chinese context borders on the overlapping THM encapsulated by Po et al. (2016), where universities have direct links with industry, whereas the government, by offering incentives, encourages academia and industry to perform beyond their traditional functions. This overlapping pattern provides more efficiency in the long term in the Chinese context because the three stakeholders are supporting each other based on coordination, collaboration, and resource provision but also ensures sufficient space of autonomy and flexibility in forging collaborative relationships. It is neither the statist model where government fully controls both academia and industry in the collaborative arrangement and resource allocation, nor the laissez-faire model in which government, industry, and academia are unable to form effective solidarity due to independence from each other (Etzkowitz & Zhou, 2017). As the data showed, such an implementation has been effective in leading to an educational innovation ecosystem where students' learning patterns and contents have been revolutionized, generating an effect greater than the sum of what each part alone could achieve. Such an effect is an important aspect of synergy (Beutell & Gopalan, 2019; Rusk et al., 2018).

The whole process of collaborative education involves cash flow from the government to enterprises, from the government to universities in direct and indirect ways, and also between the universities and enterprises in various manifestations. Despite some cost-efficiency issues such as the incompatibility between cost and returns for faculty members, our data have shown that the transaction and operation costs during the implementation of the collaboration are worth it, in that compared with China's own past, they have helped develop a collaborative education ecosystem. Such an ecosystem has been called for in Chinese academia for many years but only have been primarily developed since 2017. It showcases that universities now are not alone in educating students as ivory towers. They can get support from other stakeholders albeit imperfection. Overwhelmingly, China has tried exploring a model that have shown conducive to the improvement of higher education quality.

Conclusion and implications

Given that research has largely focused on university–industry partnerships in Western contexts (Sá, 2011; Sharabati-Shahin & Thiruchelvam, 2013), this study shifts the attention to relevant policy enactments in an Asian context using China as an illustrative case. Analysis of the policy documents sheds light on the perspectives of policymakers, and interviews illuminate the perspectives of government functionary, company project managers, and university faculty and staff members who are key to the policy implementation.

Our analysis demonstrated the significance of a synergistic approach to university–industry collaborative education in reducing the disconnection between academia and industry. Despite the different interests of industry and higher education, enterprises are directed through policy mechanisms to improve higher education quality as one of their important goals, exactly the impetus universities need to ensure quality improvement. Higher education reform, a frequently cited slogan across many countries, rests upon a better integration of the strengths of stakeholders. Still, such integration must be premised on attending to both short-term and long-term interests of every stakeholder involved. In the current age of Industry 4.0, enterprises need to recruit higher caliber engineering graduates to ensure they keep up with the rapid technological development in both the immediate and long term. Universities are under pressure to value and implement the training of applied engineering skills. However, due to the innate properties of universities as "ivory towers" distant from practice, the transition from a theory-driven approach to a practice-driven approach is not likely to take place without industry playing its part to bring practical elements as education partners and to form a dynamic and ongoing interaction pattern with the higher education sector. Beneath the ostensible failure in collaboration or synergy, which frequently happens in many university–industry partnership cases, is the disregard for costs and gains in engagement. As such, the government's role as financer, enabler, coordinator, and motivator is pivotal as it significantly mediates all collaboration practices.

Several provisional implications may be drawn. First, engineering programs should emphasize external engagement and educational collaborations to provide increasing pathways and linkages for students to engage with various authentic engineering practices. Stable and long-standing partnerships with the industry help inform the engineering curriculum agenda against the backdrop of rapid technological advancement. Second, effective coordination between stakeholders with substantive resource support is a precondition for the synergistic approach to education. Due to the profit-driven nature of enterprises, governmental policies on guiding university–industry partnerships should put value both on immediate gains and the long-term returns to provide effective incentives.

Appendix: documents analyzed

(1) Opinions on Deepening Industry-education Integration by the State Council
http://www.gov.cn/zhengce/content/2017-12/19/content_5248564.htm

(2) On Accelerating the Development of New Engineering Education for the Cultivation of Extraordinary Engineers (Plan 2.0) by Ministry of Education, Ministry of Industry and Information, the Chinese Academy of Engineering
http://www.moe.gov.cn/srcsite/A08/moe_742/s3860/201810/t20181017_351890.html

(3) 'Fudan Consensus' of the New Engineering Education Initiative
http://www.moe.gov.cn/s78/A08/moe_745/201702/t20170223_297122.html

(4) 'Tianda Action' of the New Engineering Education Initiative
http://www.moe.gov.cn/s78/A08/moe_745/201704/t20170412_302427.html

(5) 'Beijing Guide' of the New Engineering Education Initiative
http://news.sciencenet.cn/htmlnews/2017/6/379053.shtm

(6) University-Industry Collaborative Education Program Notification by Ministry of Education
http://www.moe.gov.cn/srcsite/A08/s7056/202001/t20200120_416153.html

(7) 'Tianda Scheme 2.0' for New Engineering Education Initiative
http://news.tju.edu.cn/info/1002/52034.htm

(8) Announcement of Guidelines for Enterprise-supported Collaborative Education Projects (the first batch in 2020) by Ministry of Education
http://www.moe.gov.cn/s78/A08/tongzhi/202010/t20201015_494734.html

(9) Notification on Soliciting University-industry Collaborative Education Projects in 2020 by the Ministry of Education
http://www.moe.gov.cn/s78/A08/tongzhi/202005/t20200529_460209.html

(10) Notification on Soliciting University-industry Collaborative Education Projects in 2019 by the Ministry of Education

http://www.moe.gov.cn/s78/A08/tongzhi/201903/t20190314_373380.html

(11) Notification on Soliciting University-industry Collaborative Education Projects in 2018 by the Ministry of Education

http://www.moe.gov.cn/s78/A08/tongzhi/201802/t20180227_327907.html

(12) Notification on Soliciting University-industry Collaborative Education Projects in 2017 by the Ministry of Education

http://www.moe.gov.cn/s78/A08/tongzhi/201701/t20170113_294778.html

(13) Announcement of University-industry Collaborative Education Projects (the second batch in 2019)

http://www.moe.gov.cn/s78/A08/tongzhi/202006/t20200611_464886.html

(14) Announcement of University-industry Collaborative Education Projects (first batch in 2018)

http://www.moe.gov.cn/s78/A08/tongzhi/201810/t20181030_353195.html

(15) Announcement of Qualified Enterprises for University-industry Collaborative Education (second batch in 2020)

http://www.moe.gov.cn/s78/A08/tongzhi/202012/t20201224_507448.html

(16) Announcement of University-industry Collaborative Education Projects (first batch in 2020)

http://www.moe.gov.cn/s78/A08/tongzhi/202103/t20210324_522389.html

(17) Announcement of Guidelines issued by Enterprises on University-industry Collaborative Education Projects (first batch in 2020)

http://www.moe.gov.cn/s78/A08/tongzhi/202010/t20201015_494734.html

Funding The funded was provided by the National Social Science Fund Youth Project (Grant No: CIA210268).

Declarations

Conflict of interest No potential conflict of interest was reported by the authors.

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