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Research Hotspot of Emerging Engineering Education (3E) Based on Word Frequency Analysis and Visualization Co-word Network Graph*

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***Abstract*—Emerging Engineering Education (3E), as an important measure to deepen the higher engineering educational reform, has been proposed to overcome the challenges derived from the emergence of new economy and national industrial development. To date, 3E is the most extensive and creative reform mode in the field of Chinese higher engineering education. However, relevant studies about 3E still remain at the preliminary stage. In addition, despite multiple strategies have been proposed (e.g., "Fudan consensus", "Tianda action", "Beijing guidelines", and "Thousand student plan" initiated by CDIO alliance) and have achieved considerable experiences which are highly valuable for the future development of 3E, the general views about 3E construction in China are still relatively macro; and further cogitations as well as analysis about how to implement these polices are also required. Regarding to the abovementioned concerns, herein, a quantitative research was made on the relevant literatures of 3E in recent two years in China so as to provide applicable benefits to promote the development of 3E. Based on the CNKI database, through co-occurrence analysis, factor analysis, cluster analysis, and multi-dimensional analysis of the high-frequency keywords, it is found that the future research on 3E construction will focus on integrated/joint development, multi-aspect development of 3E assessment, and refactoring development of 3E knowledge system.**

Keywords—Emerging Engineering Education (3E); educational reform; word frequency analysis

I. Introduction

Emerging Engineering Education (3E), as an important measure to deepen higher engineering educational reform, has been proposed to face the challenges deriving from the emergence of new economy and the demand of national industrial development. To date, the 3E is the most extensive and creative reform mode in the field of Chinese higher engineering education. It has attracted increasing attention since it was put forward for the first time in 2016. And also, multiple strategies such as "Fudan consensus", "Tianda action", "Beijing guidelines", and "Thousand students plan" initiated by CDIO alliance are being fulfilled so as to provide valuable experiences for the sustainable development of 3E in the future.

The "emerging" word of 3E is both a broad concept and a dynamic concept. Broadly speaking, 3E refers to three disciplines including “newly-developing”, “renascence”, and “new pattern”. [1] Regarding the dynamic state, it means the continuous improvement and update of engineering discipline construction and talent cultivation in order to maintain the "new" status of engineering discipline and talent cultivation. On the other hand, the "emerging" of 3E signifies the new modalities of engineering, for instance, "engineering +" "engineering + new concept", as well as "engineering + new technology". [2] Zhong reveals that 3E is actually a new reform direction of education proposed for the future development of China's engineering.

Although the definition of 3E is still at a controversial stage, it is highly desired to carry out in-depth research on 3E at multiple levels, because the students' acceptance of 3E requires rigorous courses, teaching, and evaluation. And also, the process of scientific inquiry and engineering design needs to be deeply integrated in practice. Furthermore, it is necessary for students to possess good discipline professionalism and the abilities to solve complex issues in the future development of the new economy.

However, the domestic research on the construction of 3E is still at the macroscopic level of overall thinking,

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without forming a specific theoretical view and an effective practice model. In view of this, in this work, taking literatures on 3E collected form CNKI (China National knowledge Infrastructure) as the research sample; it is necessary to investigate the current research status of 3E in China by using word frequency analysis and visualization co-word network graph. Notably, it is needed to predict and judge the future development direction of 3E, which might provide significant benefits for the 3E program officially entering the operational phase.

II. VISUAL ANALYSIS OF NEW ENGINEERING EDUCATION RESEARCH

In this research, the literatures about 3E in the CNKI database was collected and used for following analysis. Specifically, this research was conducted under the theme of "Emerging Engineering Education", as a result, there was 442 related documents were retrieved as of Feb. 25, 2019.

III. THE DISTRIBUTION OF AUTHORS AND THEIR ORGANIZATIONS

To make our research more convincible, it is necessary to evaluate the first author of 80 CSSCI academic papers. Among the 59 authors, there were 8 people who have published more than 2 papers, including 7 papers by Jian Lin, 2 papers by Guodong Lu, Min Ye, Peihua Gu, Baoguo Zhang, Yiqiu Wang, Zongli Jiang, and Xiaokun Jiang. All the others only published 1 paper, accounting for 86.4% of the total authors. Previously, the American statistician Lotka A J pointed out that there was a certain relationship between the number of authors and published papers, and if the ratio (the number of those who have published only one paper to the total author number) was larger than 60%, it would be considered as that no core teams have been established in this field. [3] Therefore, the 3E research in China did not form a stable core teams, long-term in-depth studies and more efforts should be dedicated in this field in the future.

Then, it is necessary to evaluate the institutions of these papers, severing to understand the distribution of major organizations or teams in this field. As can be seen in "Fig. 1", 16 institutions have published two or more papers; among them, Tsinghua University contributed the most, reaching 10 papers. Besides, Zhejiang University and Tianjin University published 6 and 5 papers, respectively. Collectively, it could be speculated that the backbone of this field was mainly concentrated in colleges/universities, especially famous universities such as Tsinghua University. On the other hand, in the past two years, with the mutual establishment of "Fudan consensus", "Tianda action" and "Beijing guidelines", the spring of higher engineering education reform in China is coming.

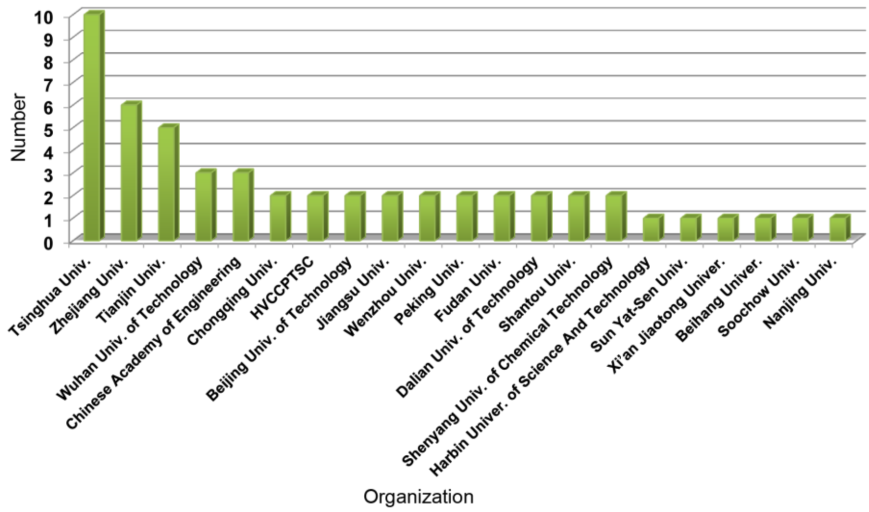

Fig. 1. The organization distribution of 80 CSSCI academic papers. Univ. is the abbreviation of University. HVCCPTSC is the abbreviation of Higher Vocational College Computer Professional Teaching Steering Committee.

TABLE I. THE HIGH-FREQUENCY KEYWORD DISTRIBUTION OF 3E RESEARCH

S/N	Keywords	Frequency	S/N	Keywords	Frequency
1	Emerging Engineering Education	225	11	Innovation Capability	10
2	Talent cultivation	41	12	Engineering Majors	10
3	Engineering Education	29	13	Cultivating Mode	9
4	Teaching Revolution	20	14	Cooperative Education	8
5	Innovation & Entrepreneurship	15	15	Engineering Talent	8
6	3E Construction	13	16	Local Universities	8
7	Higher Engineering Education	11	17	Integration of Production and Education	7
8	Practice Teaching	11	18	Talents Cultivation	7
9	"new engineering"	11	19	Professional Construction	7
10	New Economy	11	20	College-enterprise Cooperation	7

TABLE II. THE COLLINEAR MATRIX OF HIGH-FREQUENCY KEYWORDS OF 3E

Keywords	3E	Talent Cultivation	Engineering Education	Educational Reform	Innovation & Entrepreneurship	3E Construction	Higher Engineering Education	Practical Teaching
3E	226	31	26	18	15	0	6	12
Talent Cultivation	31	41	3	4	4	2	0	0
Engineering Education	26	3	29	0	1	2	0	0
Educational Reform	18	4	0	21	0	0	1	2
Innovation & Entrepreneurship	15	4	1	0	15	0	0	1
3E Construction	0	2	2	0	0	13	0	0
Higher Engineering Education	6	0	0	1	0	0	12	0
Practical Teaching	12	0	0	2	1	0	0	12

TABLE III. THE SIMILAR MATRIX OF HIGH-FREQUENCY KEYWORDS OF 3E

Keywords	3E	Talent Cultivation	Engineering Education	Educational Reform	Innovation & Entrepreneurship	3E Construction	Higher Engineering Education	Practical Teaching
3E	1	0.1037	0.1031	0.0683	0.0664	0	0.0133	0.0531
Talent Cultivation	0.1037	1	0.0076	0.0186	0.026	0.0075	0	0
Engineering Education	0.1031	0.0076	1	0	0.0023	0.0106	0	0
Educational Reform	0.0683	0.0186	0	1	0	0	0.004	0.0159
Innovation & Entrepreneurship	0.0664	0.026	0.0023	0	1	0	0	0.0056
3E Construction	0	0.0075	0.0106	0	0	1	0	0
Higher Engineering Education	0.0133	0	0	0.004	0	0	1	0
Practical Teaching	0.0531	0	0	0.0159	0.0056	0	0	1

TABLE IV. THE DIFFERENT MATRIX OF HIGH-FREQUENCY KEYWORDS OF 3E

Keywords	3E	Talent Cultivation	Engineering Education	Educational Reform	Innovation & Entrepreneurship	3E Construction	Higher Engineering Education	Practical Teaching
3E	0	0.8963	0.8969	0.9317	0.9336	1	0.9867	0.9469
Talent Cultivation	0.8963	0	0.9924	0.9814	0.974	0.9925	1	1
Engineering Education	0.8969	0.9924	0	1	0.9977	0.9894	1	1
Educational Reform	0.9317	0.9814	1	0	1	1	0.996	0.9841
Innovation & Entrepreneurship	0.9336	0.974	0.9977	1	0	1	1	0.9944
3E Construction	1	0.9925	0.9894	1	1	0	1	1
Higher Engineering Education	0.9867	1	1	0.996	1	1	0	1
Practical Teaching	0.9469	1	1	0.9841	0.9944	1	1	0

IV. SUBJECT ANALYSIS OF 3E

A. The Frequency Statistics of High-frequency Keywords

Afterward, it is needed to extract and count the keywords of these papers by using the Bicomb 2.0 software. As a result, these obtained 100 keywords presented the total frequency of 702 times. In order to eliminate the influence coming from qualitative factors and reflect the author group consensus degree toward certain keywords as much as possible, no keywords have been deleted, and the synonyms were also not merged. In this research, keywords appearing more than 6 times are regarded as high frequency words. As illustrated in "Table I", 20 high frequency words were obtained. The total presentation frequency of them was 468, accounting for 66.7% of the total frequency of all keywords. Among them, the top 10 was new engineering, talent training, engineering education, educational reform, innovation/entrepreneurship, 3E construction, higher engineering education, practice teaching, "new engineering", and new economy.

B. Co-word Matrix

To evaluate the correlation between keywords, it is needed to assess the collinear matrix, similar matrix, and different matrix of the high-frequency keywords by importing the catalog into SATI. Significant correlations between 3E and talent training, engineering education, educational reform, as well as innovation/entrepreneurship were noted, as indicated by the co-occurrence frequency in which the higher frequency suggests the closer the relationship between two keywords (see "Table II"). Moreover, similar results were also obtained in the high frequency keyword similarity matrix of 3E research (see "Table III"), in which the closer the value to 1, the closer the relationship between the two keywords. It is necessary to carry out the multidimensional scale analysis by using the difference matrix (see "Table IV"). In this case, the closer the value to 0, the relationship between the two keywords was more distant.

C. Multidimensional Scaling Analysis

Then, the research structure of 3E was investigated by the multidimensional scale analysis. After importing the dissimilar matrix of high-frequency keywords into SPSS 20.0, the hot knowledge map of 3E was obtained. According to the relative density of the key words, it is needed to find that the studies of 3E were mainly concentrated in the field of the combination of engineering education and practical application.

D. Visualization Co-word Network Graph

In general, the co-word network map can reflect the overall characteristics of the common word network intuitively and clearly. In the co-word network graph, each node represents a keyword, and each line indicates the relationship between two keywords. In other words, when two keywords appear together in one paper, the arrow indicates the direction of the relationship, and the number of connections means the number of other keywords associated with a certain keyword. Based on these, it could be intuitively observed that the 3E was at the center of the whole co-word network diagram, suggesting that it connected with almost all other keywords. Besides, practical teaching, cross-border integration, innovation, talent training, cooperative education, integration, cooperation between colleges, and secondary school education also possessed closed relationship with other keywords. Therefore, it is necessary to speculate that researchers have paid many efforts in these fields, so it was able to infer that these keywords are the research hotspots in the field of 3E in China. Notably, engineering science and technology talents, talent training mode, as well as interdisciplinary integration were in the middle of the Co-Word Network Graph, which behaved the core bridge to connect the central key words and the marginal key words.

Meanwhile, some other key words, such as intelligent manufacturing, art education, the technical advantages of colleges and universities, new curriculum construction, building intelligence engineering, flipped classroom, 3E research and practice, were localized in the edge and had little contact with other keywords. But this phenomenon did not suggest these keywords were not important or not worth researching. Contrarily, they might represent the future research direction and trend of 3E, because most of these keywords were counted from the recently published papers, thus deserving more attention in this research.

V. FUTURE RESEARCH DIRECTION OF 3E

A. Integrated Development of Emerging Engineering

The integrated development of 3E involves two expects. One is the "stock update", [3] also known as new engineering major, aiming at getting rid of the previous “pure” engineering talent training mode through constantly upgrading, renovating, and renewing the conventional engineering majors. It emphasizes the intersection and integration of existing engineering majors with other disciplines, and focuses on the cultivation of compound and comprehensive talents in order to gradually adapt to the future requirements of economic industrialization. However, for "old engineering", its knowledge systems are outdated, lacking of the flavor of ere of times. Besides, regarding the perspective of structure, its discipline categories are rigidly divided and the discipline majors are divided too finely. Moreover, in the mechanism point of view, “old engineering” also fails to meet the demand of the development of the market and industry closely, and lacks of flexibility on subject setting.

With the arrival of the forth new industrial revolution, it would be a positive response to "made in China 2025" to promote the all-round reform of higher engineering education, and strengthening the cultivation of innovative talents as well as improving multidisciplinary cross and integration have become the core of 3E in the future. More importantly, it is also the major strategic measures to seek the international competitive advantages under the background of new economy and to realize the higher engineering education reform.

The second is the "incremental replenishment", which refers to the emerging engineering majors, a new discipline arising from the cross-integration between engineering disciplines or engineering discipline with other disciplines, for instance, the integration of machinery and computer. Actually, these cross-integrations cater the development needs of modern industry. While the cross integration of engineering and natural science enriches the connotation of engineering to a certain extent and gives more development space. In detail, the "Emerging" term of 3E is regarded as the unprecedented new discipline which is conceived, extended and expanded from non-engineering disciplines. At present, such kind of discipline is still in its early development stage, and its connotation and characteristics are still not clear. However, the new technologies such as new materials and new energy generated during its development also form a number of emerging industries (e.g., photovoltaic, lithium ion, and more).

3E is proposed to better train the innovative talents with good scientific literacy for the country, instead of the mere combination of related subjects. The integrated emerging engineering education not only contains the "stock update", but also the "incremental supplement", which is an organic combination of them, suggesting the integration of emerging engineering specialty, renascent engineering specialty, and new-type engineering specialty. Obviously, the goal of 3E is not only to train a batch of scientific and technological talents with innovation and entrepreneurship ability and cross-border integration potency, but also to provide "scientific literacy +X" composite excellent talents who are highly required in the new economic era.

B. Partner Development of Emerging Engineering Education

The integration characteristic of 3E determines that it must establish four cooperative partnerships in the development process, namely the college-enterprise cooperative partnership, the university-government cooperative partnership, the university-research institute cooperative partnership, and the international cooperative partnership. The establishment of these four partnerships is of great significance for the long-term development of 3E. For universities, enterprises have the following two advantages in talent cultivation: firstly, they have a keen sense that can accurately grasp the changing trend of national demand for engineering talents under the new economic background. Secondly, students can make up for their theory embarrassment from practice, and meanwhile, both the production equipment and advanced manufacturing technology are able to let students having the feeling that everything is new and fresh, and good enterprise culture atmosphere can bring students into the real engineering practice, thus under the guidance of professional engineering and technical division, students finally complete the wonderful engineering practice journey. [4] Therefore, the establishment of college-enterprise cooperative partnership is not only conducive to the further improvement of engineering talent training mode, but also greatly improves the quality of engineering education.

The partnership establishment between the government and universities can connect their engineering construction together, thus making the 3E construction receiving the attentions and supports from the government departments during its development process. This has played a positive role in promoting the reform of the emerging engineering education system and mechanism, optimizing the structure of discipline professional, reforming the personnel training mechanism, and strengthening the construction of the teaching staff. The establishment of the cooperative partnership between universities and the government not only provides a favorable policy environment for the development of 3E, but also breaks the policy barriers to a certain extent and gradually realizes the new pattern integrating politics, industry, education and research. At the same time, the engineering talents cultivated by universities can considerably support the implementation and implementation of government industries and related policies and measures. And also, benefiting from the 3E construction, universities can make them a leading role in the future direction of industrial development, which has a positive effect on the government's formulation of relevant industrial policies.

In the cooperative relationship between universities and research institutes, the research institutes have demonstrated their advantages in the process of cooperative education. For example, most subjects of the research institutes are related to new industries, and at the same time, significant information about new industries has been accumulated in the process of in-depth studies. Generally, some of the conditions that scientific research institutes have are necessary for the professional construction of the new engineering sciences, such as new technologies, good research environment, researchers who are skilled in operating mechanical equipment, and so on. The good partnership established between universities and industry-related research institutes can not only makes up for the severe deficiencies of universities, but also achieve resource sharing to a certain extent. This will be of great significance for promoting the further collaboration and orderly development of the project in universities and research institutes.

Although the construction of new engineering has to adhere to the "rooted in China" and "local characteristics", the future development direction of the new engineering should be oriented to the world, which is determined by the characteristics of the emerging engineering (e.g. innovation, development, cross-border, and leading). By international cooperation, the international advanced education concepts and school-running ideas should not only be on learning, but also on their ability to construct a new engineering talents training system that is localized in China, and establish/improve the corresponding engineering discipline professional certification system.

C. Multifaceted Development of 3E Evaluation

Quality evaluation plays a highly important role in ensuring the quality of talent training in universities. Then to understand the quality evaluation of emerging engineering education, it is needed to make clear three questions: What is the quality standard system for 3E, and how to build and improve it? What is the progress of the work on standards for talent training? How to achieve the newly established 3E quality evaluation system that can not only be in line with international standards but also have local characteristics in China? For the first issue, the main opinion of the academic circle is to refer to the quality training standard system of the "Excellent Engineer Education and Training Program" (abbreviated as EEETP) proposed by the Ministry of Education in June 2010. It consists of three parts: the national standards formulated by the Ministry of Education and the relevant national ministries or engineering institutes, the industry standards formulated by the industrial departments or associations based on national standards, and the school standards set by universities. Lin suggested that the quality standard system in EEETP has certain reference significance for building the quality standards for the training of new engineering majors. [4] This will place higher demands on students in terms of subject knowledge, professional competence, and other comprehensive qualities.

The implementation of personnel training standards is also mainly based on the EEEPT, which involves three processes. The first is to gradually decompose and standardize the training standards of college professionals; the second is to implement the curriculum and teaching links; the last is to further improve the talent training program. However, in China, it has not yet defined a uniform definition of the quality standards of future engineers. The quality evaluation system for new engineering education has not been established yet. Hence, it is required to expand the previous professional catalogue of engineering education certification, and at the same time, for the "new" engineering major, the traditional engineering education certification professional catalogue is slightly outdated, which requires transformation, improvement, and upgrades to match the "emerging" engineering profession. Whether it is the addition, replacement or revision of the certification common standard, the purpose is to establish a more systematic and comprehensive new engineering education quality evaluation system.

For the establishment of the new engineering education quality evaluation system, the industry standard may be considered as a reference factor on the basis of the original engineering education certification system, so that the renewal and transformation of the existing engineering education certification system can be completed. Moreover, this will make the newly established new engineering professional certification system more targeted. In addition, with the development of new engineering education, its unique development model and corresponding evaluation method have gradually formed. Therefore, “results evaluation” should not be emphasized as in the past, but should insist on “result evaluation” and “process evaluation” simultaneously, which is in line with the new educational philosophy of the new engineering discipline. The talents cultivated are no longer only good at exams, but excellent talents with various kinds of abilities. At the same time, in the process of insisting on the evaluation of students in the school, it is needed to pay attention to the external evaluation of students. Only in this way can the evaluation result be more complete, objective and authentic.

The construction of new engineering is mainly carried out through the form of the project, so it is particularly important to construct the project evaluation system for 3E. In view of stage, the project evaluation of 3E is generally divided into the annual inspection phase, the mid-term inspection phase, and the project acceptance phase. [5] From a formal point of view, project evaluation generally has three forms: written report, on-site inspection, and exchange review. While from the main body of the project evaluation, there are mainly new engineering research/practice expert group (work group), excellent engineer education training program professional evaluation expert, engineering professional certification expert, teaching & pointing committee, and enterprises or third parties. The ultimate goal is to gradually improve the practical operation level of the project work so that it can achieve effective outcomes in accordance with the established goals, on the basis of ensuring the smooth progress of the new engineering project.

In conclusion, there are three issues should be emphasized toward the quality evaluation of emerging engineering education. Firstly, the quality evaluation subject of 3E should present a diversified trend; Secondly, the quality evaluation method of 3E should be specific. Thirdly, the quality evaluation results of new engineering education should not be shelved, but should be applied to the continuous improvement of quality.

D. The Refactoring Development of 3E

For the understanding of the reconstruction of the new engineering knowledge system, it is necessary to clarify three issues, namely: first, what is the existing engineering knowledge system structure? Second, why should we refactor the new engineering knowledge system? (3) How should colleges and universities carry out the reconstruction of the new engineering knowledge system? For the first question, Xuesen Qian published his understanding of the structure of engineering knowledge system in 1979, and proposed the "1+5" architecture. He has put forward that engineering technology is always closely related to the country's economic development, and no matter the engineering technology is integrated into the natural sciences or the social sciences, it seems slightly inappropriate. So, it would be better for engineering technology to be an independent system. On the basis of the above statements, Qian finally established the "1+11 comb-shaped scientific architecture" in the 1990s. And then, under the in-depth research of famous scholars such as Guangyuan Yu, Zhongxiu He, Zhifeng Xu, and other scholars, China's engineering knowledge system structure began to gradually transform into systemic science and cross-disciplinary science, eventually showing a tetrahedral tower-like structure of the scientific department. [6]

For the second question, under the context of society, new knowledge begins to develop exponentially, and the transformation cycle of knowledge results is also shortened. Therefore, coupled with the emergence of some interdisciplinary and interdisciplinary subjects, the existing and existing knowledge systems cannot adapt well to the social development of the new economic era. On the other hand, the existing engineering education courses are relatively old-fashioned and cannot be well integrated with classroom learning and engineering practice. Besides, the division of disciplines is too detailed, and the existing disciplines are still set up in the past hierarchical structure, which cannot enrich students' professional cognition, as a result, leading to a great hindrance to the cultivation and promotion of students' compound ability. From the perspective of mechanism, the adjustment of disciplines and professions seems to be dull in the past, and at the same time, it does not pay close attention to the market demand situation in the new economic era as well as the changes in the demand for talents in future industrial development.

From the perspective of the core elements of the quality of future engineering talents, although the core elements of the future engineering talents have not yet been clearly defined, based on the "Engineering of 2020: The Vision of the New Century Project" issued by the American Academy of Engineering, the 2016 Century Economic Forum report, and the research of Chinese scholars, the core elements can be divided into the following categories: interdisciplinary integration, communication and negotiation, learning, leadership, independent lifelong learning, etc. [7] Obviously, the talents cultivated in the past engineering knowledge system can no longer meet the development needs of the future market and industry.

For the third question, Xinhe Bao academician has already given us the answer. He said: "In the aspects of reconstructing the core knowledge of the new engineering, if there was no general knowledge, the new engineering construction will not go down." [8] Consequently, the effective combination of professional education and general education is not only the purpose of reconstructing the new engineering knowledge system, but also the guiding light that guides our next work. [9]

After comparing the relationship between general education and professional education, it is necessary to find that universities have a common understanding, such as advocating general education for college engineering students, advocating strengthening the deep understanding of the inclusiveness and expansibility of professional education. [10] This is highly important for college engineering students and major strategic needs of our country no matter in the aspect of promoting the students’ understanding of scientific knowledge or further enhancing the humanities quality of students. Strengthening general education can deepen students' understanding of professional education, and meanwhile, the further deepening of professional education puts forward higher requirements for general education. [11] The synergy effect of general education and professional education should be fully exerted, so that this road of new engineering education can not only go on, but also be more stable and longer.

VI. CONCLUSION

This paper mainly analyzes and summarizes the research orientation of China's emerging engineering education through the quantitative analysis, cluster analysis, and factor analysis of high-frequency keywords in emerging engineering education, and makes predictions and judgments on the future development direction of 3E. The current research orientation is characterized as theoretical unity, research mix, and school category diversity and implementation gap. The future direction of new engineering education research is the integration development, partner development, the multi-faceted development, and the reconstruction of knowledge system.

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