International Journal of Engineering Education Vol. 36, No. 6, pp. 1988–1995, 2020
Printed in Great Britain
0949-149X/91 $3.00+0.00

A New Approach for Engineering Education Reform of Power System*

XIANGYU KONG[1]**, WENQI LU[1], QI GUO[2], YIHUA ZHU[2], FANG ZHANG[1] and BIN LI[1]
[1] School of Electrical Engineering & Information, Tianjin University, Tianjin 300072, China.
[2] State Key Laboratory of HVDC (Electric Power Research Institute of CSG), Guangzhou 510663, Guangdong, China.

While Industry 4.0 is quickly transforming the modern industrial landscape, the traditional education model is facing significant challenges. In order to train the talents to meet the needs of new industrial development, this paper takes the course of electric energy production as an example and puts forward the operable teaching reform methods. First of all, according to the development trend and demand of power system industry, some critical issues of education reform are condensed. Secondly, based on the proposed new engineering teaching evaluation standards, a new approach for engineering education reform of power system are designed, and the teaching content, practical teaching methods and classroom teaching methods are improved. Through the comparison of actual education results, the effectiveness of the proposed method is verified. Finally, some useful concludes are provided in the paper.

Keywords: power system; talent cultivating; new engineering disciplines; experimental courses; teaching reform

1. Introduction

1.1 Background of the Talent Cultivating Mode

With the rapid development of Industry 4.0, applications such as cloud computing, the Internet of Things, and big data have rapidly expanded, putting forward unprecedented demands on the current full-chain development. Thereby it also promotes essential changes in the future engineering field. "Reform and opening, education first," engineering education must seize the opportunities of the development of new industry and technology and meet the engineering field's need. The reform of talent training models needs to be promoted vigorously and help to transform the economic model from the traditional economy to a new one [1].

Talent cultivation means a process of cultivating qualified personnel by adopting certain methods based on specific goals. Teaching reform refers to the reform process of changing teaching content, improving teaching methods, adopting new teaching techniques, etc. to achieve new teaching goals. When facing the rapid development, no matter how great engineering activities must ultimately be achieved through "talents". Engineering education is a "bridge" linking engineering activities and talents, and a model for training engineering talents is the specific path to step across this "bridge". However, when it comes to the cultivating of engineering talents, there are still situations that deviate from the actual needs of the industry [2]. The reform of higher education in the power system specialty of engineering universities needs to be consistent with industrial development to meet the demand for talents in the development of the new economy [3].

1.2 Background of the Practical Education

Practical education can better promote the development of engineering discipline based on the real-case investigations. This paper takes the course named "electric energy production process" at Tianjin University (TJU) in China as an example to research and analysis, and guide the future development of engineering disciplines purposefully.

The problems of practical power system education are including teaching method and teaching content, as shown in Fig. 1. Students face a lack of interest in learning, challenging to understand the theoretical knowledge, and lack of multiple assessments and deep impression. Most of the content is on the traditional power system, and the lack of new technology development of the introduction affect students keep up with the pace of development.

The power system course focuses on the underlying theory and calculation methods of the composition, design and operation of the central electrical system. However, the specific details of the power conversion and production process of various types of power plants are not discussed, which also causes students to have difficulty in understanding knowledge [4]. Traditional education content mainly bases on the thermal power, hydropower, and nuclear power parts, but renew-

** Corresponding author: Xiangyu Kong, Staff of Key Laboratory of Smart Grid of Ministry of Education in China, School of Electrical Engineering & Information, Tianjin University, No. 92 Weijin Road, Naikai District, Tianjin, 300072, China. E-mail: eekongxy@tju.edu.cn

* Accepted 13 June 2020.

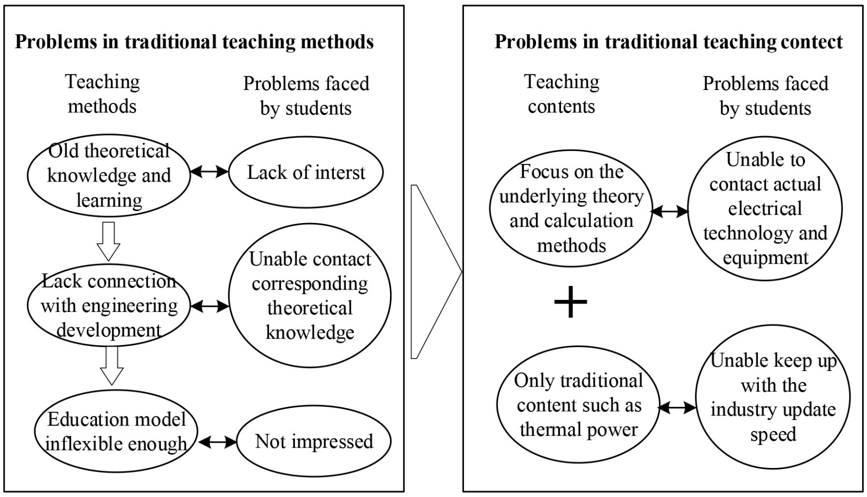

Fig. 1. Problems of practical power system education.

able energy has gradually become the focused object of electricity. It is necessary to add more emerging content to the teaching, such as knowledge related to wind power, solar energy, tides, bioenergy, etc. Teachers educate students on the principles, equipment, and processes related to energy conversion, and use multimedia technology, such as related videos. Besides, when students go to the substation for experimental learning, they may find that many devices and techniques cannot be found in the textbooks. Therefore, it is necessary to introduce the latest content and trend to students when guiding them to visit or experiment.

1.3 Literature Analysis

Regarding reforms for the development of new engineering disciplines, many studies have been carried out at home and abroad.

In terms of the reform direction of the development of new engineering disciplines, Tianjin University Action comprehensively summarizes seven areas where modern engineering needs to be improved. It includes the new paradigm of engineering development, the unique structure of engineering specialty, the new knowledge system of engineering talents, the innovative methods of engineering education, the new mechanism of school subjects, the ecology of engineering education, and the new international frontier [5]. Gu [6] believes that the most critical aspects of the new engineering discipline are reflected in new ideas, new models, new quality, new content and new methods. Ye et al. [7] analyze the characteristics of the new engineering discipline based on the future "new format", which is from technology, scale, politics, industry and humanities five dimensions. Lin Jian [8] further enriches the connotation of the new engineering discipline from the eight aspects including education and teaching philosophy, professional discipline structure, professional discipline construction, talent cultivating mode, multi-party cooperative education, practice innovation platform, teacher team construction and genius growing quality. Zhong [10] expounds the critical points of the new engineering reform from philosophy, requirements and approaches three elements.

The other scholars introduce the inspiration brought by a specific type of engineering education experience. For example, Yuan [11] proposes the development path of integration of new engineering disciplines and combination of industry, teaching and research. Hu [12] summarizes the implementation path of new engineering construction by learning from the training characteristics of STEAM education. Ye et al. [13] believe that the structure of a new engineering discipline could be transformed from idea to action by constructing a CDIO conversion platform. Kendall et al. [14] found that many factors were affecting the development of engineering identity, such as performance/ability, interest, recognition, analysis, framework and problem solving, system, gender and parents with engineering degrees. Shekhar et al. [15] use classroom observations, faculty interviews, student surveys, and focus groups to examine an engineering instructor's postworkshop implementation of active learning in an engineering course.

Regarding the new engineering teaching reform, current research results can be summarized into four aspects, the reform goal, reform direction, reform measures and influencing factors, as shown in Table 1.

The research content of technical routes for experimental teaching reform mainly includes

Table 1. Literature analysis summary

Reform goals	To cultivate talents with both knowledge and skills
	To meet the needs of the engineering industry
Reform direction	Teaching content
	Teaching model
	Teaching system
	Teaching platform
Reform method	To integrate different disciplines
	To change course content settings
	To formulate new talent evaluation standards
	To combine learning, research and production
Influence factors	Student interest
	Personal abilities (such as recognition, analysis, framing and solving problems, tinkering)
	The social environment for talent training
	Talent cultivating methods (such as group study, monotonous examination and homework, practical operation and so on)

three aspects. The first step is to modify and improve the content of classroom teaching to make it adequately reflect the current development status and trends of the power system, eliminate outdated content. The second is to supplement the new content such as the dynamics of thermal, water and nuclear power plants, as well as digital and intelligential substations and so on. The third is to research on the organization and implementation of the classroom teaching, comprehensive experimental professional training and production practice, including designing the three levels and coordinating the relationship between them, which mainly involves the following two issues:

(1) How to make teaching and experimental content, production practice, technical professional training and other aspects meet with the current development trend and production reality of the power industry and can satisfy the needs of modular structure, flexible teaching content and multi-level teaching.
(2) How to make classroom teaching, comprehensive experimental design and electric power production practice courses closely related to each other with the principle ‘‘enough theory, focus on application’’.

2. Methods Adopted

2.1 New Engineering Teaching Evaluation Standards

Engineering education graduates can be summarized from three aspects: engineering knowledge, engineering abilities, and engineering attitudes [3]. The specific standard content is shown in Table 2.

Table 2. Evaluation criteria for practical teaching for new engineering subjects

Category	**Requirement**	**Detailed information**
(1) Engineering knowledge	Engineering knowledge	Apply mathematical, scientific, foundational, and specialized engineering knowledge to solving engineering problems.
(2) Engineering ability	Problem analysis	Discover, articulate, research literature and analyze engineering issues.
	Designing/developing a questionnaire	When designing solutions to engineering problems and conducting systems, components or procedures that meet their specific needs, consider it that public health, safety, cultural, social, environmental and other factors.
	Investigating and researching	Use research knowledge and methods to investigate engineering issues, including experimental design, data analysis and interpretation, and information synthesis to draw valid conclusions.
	Application of modern tools	Create, select, and apply appropriate techniques, resources, and advanced engineering and information technology tools, use them to engineering activities, and have a thorough understanding of their limitations.
	Individual and teamwork	Effectively play an individual, member or leadership role in a variety of team and multidisciplinary contexts.
	Engineers and society	Apply rational thinking of relevant background knowledge to evaluate the impact of professional engineering practices and solutions on social, health, safety, legal and cultural issues and their resulting responsibilities.
	Communication	Be able to communicate effectively with the engineering community and the entire society in engineering activities.
	Project management and finance	Be able to apply engineering and management principles to work, effectively participate in project management in a multidisciplinary context.
(3) Engineering attitude	Environment and sustainable development	Fully understand the impact of professional engineering problem solutions on the environment and society, and demonstrate understanding and demand for sustainable development.
	Ethics	Promote ethical standards, abide by professional ethics and assume responsibilities in engineering practice.
	Life-long learning	Recognizes the need for independent lifelong learning in the context of a wide range of technological changes, and has the capacity for lifelong learning in such situations.

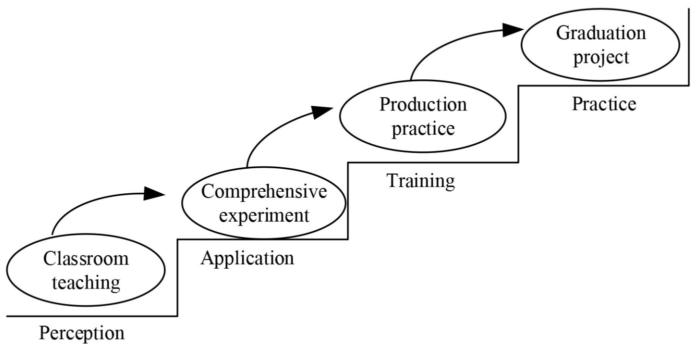

Fig. 2. Teaching structure of comprehensive experimental design and production practice.

Teachers can refer to the standards to reversely deduce the construction of the course and conduct the teaching process. With the standard and student-centered principle, the textbook-centered or teacher experience-centered evaluation method can be gradually changed.

2.2 Organization and Implementation of Education

Comprehensive experimental design and production practice education are divided into three parts: the course design link taking engineering project as the task for the full application of theory and practice; the comprehensive design link for the power system skills training; the field practice link for the ability training serving practical jobs. There are a connection and growing relationship between all links, which gradually forms an effective teaching system connected to the power system [16].

The framework of detailed experiment design and production practice teaching is shown in Fig. 2, where each practice link is provided with a project or task list.

(1) Driving and Guiding Methods for Comprehensive Experimental Design

Task-driven, industry-standard-guided comprehensive experimental design is to choose design topics derived from actual projects, abide by industry design standards, consult industry design and equipment manuals, understand industry regulations, and follow practical engineering design steps. The forming drawings of the design results, such as the main electrical wiring and more are strictly drawn following the standard drawing of the industry electrical diagrams. In this way, students are able to receive preliminary training in practical engineering design, understand national power regulations, learn to use power supply and distribution equipment manuals, and improve their ability to analyze and solve problems.

(2) Driving and Guiding Methods of Production Practice

Project-led, task-driven professional training is to take critical skills as an on-campus training project and to take electrical equipment installation, commissioning, and wiring as tasks, which is divided into different sub-project items and trained separately [17]. In the practical training process, students are required under the actual installation procedures, commissioning requirements, and wiring processes, which demands not only training skills but also job qualities. Through this way, students can master the theories of electric energy's production, transmission, coordination control after faults as well as the skill of installing and maintaining electrical equipment, application of WAMS in power system, coordination control after faults, the AC-DC hybrid system.

3. Results

3.1 Improvement of Practical Teaching Content

Instructional design is the process of using a systematic approach to analyze teaching problems and determine teaching goals, and to establish strategic solutions to solve teaching problems. The curriculum theory learning is designed to be a teaching method that integrates with essential practice. This form of teaching combines knowledge learning, ability training, and quality cultivating throughout the entire teaching process, and unites theory and practice.

The teaching content planned for improvement is selected from the knowledge required for the application field of the course and tasks in the typical working process, and it is sequenced and integrated according to the pre- and post-connection to ensure the relevance and applicability of the teaching content. Through the visit or practice, consolidate the foundational theoretical knowledge, basic master methods, and cultivate students' resilience to accept new things and innovative consciousness [18].

3.2 Application of New Practical Teaching Methods

"Electric Power Production Process" is a comprehensive and practical professional course with a

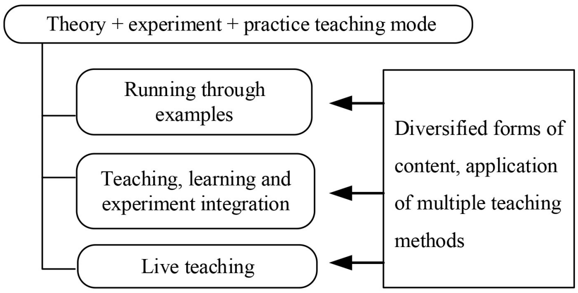

Fig. 3. Application of experimental teaching methods.

wide range of content. In the process of experimental teaching, innovative teaching methods should be invented, so that the content has the characteristics of diversified expression methods and cross-application of multiple teaching methods, as shown in Fig. 3. In the interaction of teaching, learning and exploring, students can understand and master knowledge through intuitive feelings and experiences, change "instillation" into "apperception", which can cultivate students' interest in learning and improve teaching effectiveness [19].

The proposed innovative education research methods include the followings:

(1) Penetration full-process examples. The full-process example penetration method means to select many typical cases that match the textbook content. After each knowledge module, analyze the corresponding part of examples to the content of the blade and show the detailed application of knowledge in the sample. After teaching the course, a complete model of the power production process is also thoroughly analyzed.

(2) Integration of teaching, learning and experiment. The integrated model focuses on comprehensively combining theory with practice. Take the working process as a sequence, connect the relevant course content and practice into a teaching project, and use the task-driven method to complete the teaching goals, which makes the teaching content more targeted and the teaching process more effective.

(3) Experimental participation and on-site teaching. On-site teaching is a form of education that organizes students to visit, investigate, or operate according to specific teaching tasks. When conditions permit, let students participate in part of the experimental process of new energy and smart grid laboratories, so that students can fully understand the power generation process of various power sources and related systems and equipment, and enhance their ability to operate [20].

In addition to the above-mentioned experimental teaching methods, methods like discussion teaching, intuitive teaching, and task-driven teaching can also be tried.

3.3 Improvement of Classroom Teaching Methods

Classroom display requires students to combine the knowledge and skills they have learned to present a plan and complete the task. Its evaluation indicators include the knowledge richness, skill complexity, display style, etc. during students' display process. Classroom display content is generally stipulated by teachers and then expanded by students, which is related to the primary teaching content but beyond its scope. It requires students to learn independently, organize themselves and add appropriate innovations. For example, after learning the necessary process of thermal power generation, teachers can arrange a class display task titled "New Key Technologies and Equipment in Thermal and Renewable Power Generation" [21], then students collect data, make independent thinking and display.

Fig. 4 shows the relationship between the elements of the classroom display, which is based on the curriculum evaluation goals, including teacher guidance, task display, material collection, and effect evaluation. From the teachers' perspective, first of all, teachers must design appropriate classroom display tasks and indicate the direction of the display. Teachers should make sure that the task is challenging for students, but it can be performed. At the same time, teachers should clearly express the expected goals of the classroom display. Besides, teachers need to formulate detailed scoring rules for classroom display, which includes the depth and innovation evaluation and other scoring details. It is better to give a list of explanations and send them to students before the show starts, which can help students to reflect and understand problems better through mutual evaluation. When designing and evaluating classroom display tasks, pay attention to the following aspects:

(1) The clarity of demonstration tasks and evaluation goals;
(2) The consistency of evaluation goals and evaluation rules;

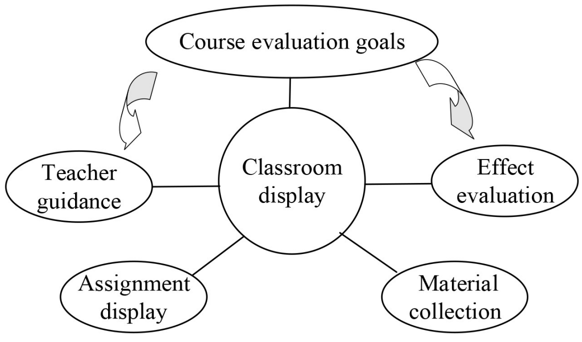

Fig. 4. Relationship between various elements in the classroom.

(3) The correspondence between demonstrates assignments and evaluation details.

3.4 *Effectiveness Analysis*

The final test paper results of all the students in the class studied are analyzed to verify whether the improvement of the new engineering classroom evaluation based on the learning results can help improve the student's learning outcomes.

Aiming to make the research results as accurate as possible, the course of "electricity production process" in the same school year is divided into five teaching classes, including three experimental classes (CC1, CC2, and CC3) and two controlled classes (EC1 and EC2). Classes and students are randomly selected to ensure the homogeneity of students; that is, the students' foundations are very close to each other. The statistics are mainly based on the final roll scores for analysis rather than the overall evaluation scores, eliminating the interference of subjective factors such as teachers' "impression points". The comparison of the test score in each class is shown in Fig. 5, and the classes test score distributions of participating in teaching reform and non-participation are shown in Fig. 6.

It can be seen that the classes participating in the practice teaching reform (CC1, CC2, and CC3) have better results than the contrast classes (EC1 and EC2). Among them, the highest score and scores above 90 of class CC3 are 20% higher than EC1. Besides, the proportion of high scores in each class is the same. Still, the minimum score and median of experimental groups are higher than the control class, and the average ratio of qualified and top is 10% higher, which indicates that classroom evaluation has a more significant promotion role in students with mid-to-late grades. The standard deviation of the experimental class is lower than that of the control class, which indicates that the teaching reform can make the student's performance distribution more uniform and concentrated, and the student's performance difference smaller.

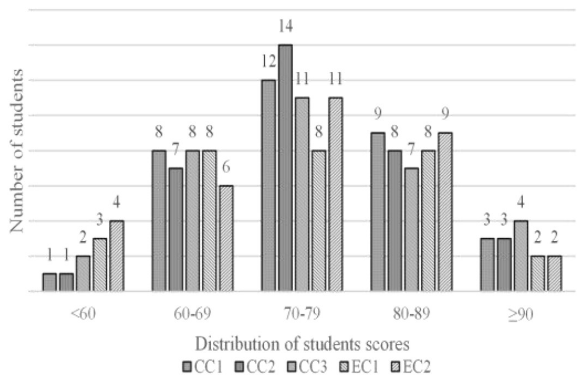

Fig. 5. Comparison of test scores of each class.

In order to further analyze the effect of the education reform comprehensively, three different groups of students made a comparative analysis. Group 1 has 60 students who participated in the teaching reform for one year; Group 2 has of 60 students who had participated in for 2 years, and Group 3 consisted of 60 students who were not involved in the reform. The contents of assessment include: (1) Engineering problem analysis ability; (2) Development and research ability; (3) Engineer cultivation ability; (4) Teamwork and leadership; (5) Technological innovation ability; (6) Lifelong learning ability. The comprehensive educational effects of different student groups is shown in Fig. 7.

Among them, engineering problems analysis ability includes the basic knowledge of mathematics, natural science and electrical engineering, and its comprehensive application in power system planning and design, scheduling management, control, fault protection and so on, which increases by 68 to 78 and 82 points through 1 and 2 years of training. Development and research ability including clearly recognizing the product production system as a whole, to master the key technology and working procedure of the design process, has engaged in preliminary ability to design and devel-

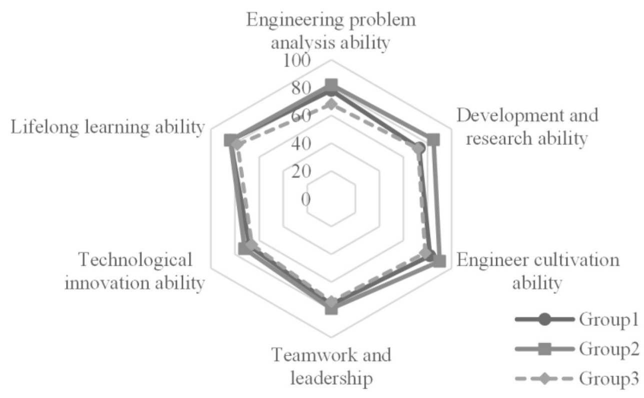

Fig. 6. Grades' normal distribution of each class.

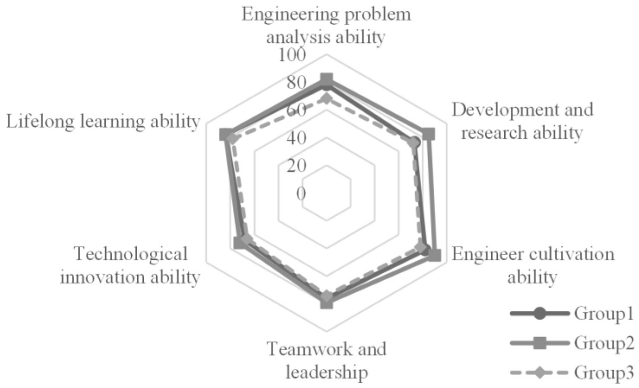

Fig. 7. The comprehensive educational effects of different student groups.

opment of new products, which increase by 62 to 73 and 85 points through training. However, other abilities, such as teamwork and leadership, include the ability to communicate effectively with team members, teamwork awareness and ability, just from 77 to 79 points. Life-long learning ability has increased from 78 to 84 points. Therefore, in the education reform, it is necessary to strengthen the internal ability training in these aspects.

4. Conclusion

Based on the background of the global engineering technology development of the Industrial 4.0, it is becoming increasingly important to obtain education experience and provide corresponding suggestions and measures for engineering education reform. This paper takes Tianjin University's "power system" practical teaching reform as an object, which is for the development of new engineering disciplines and attempts to explore the regular pattern and trends of the development of typical engineering disciplines. The conclusions are as follows:

(1) The essential goals and content of building "new engineering" is to emphasize both fundamental knowledge and significance of the practice, to attach more importance to the needs of the industry, and the comprehensive development of engineering talent capabilities

(2) In the process of experimental teaching reform, the construction of the experiment and course goal system should be improved. And personalized content should be added, which can provide students right of self-selection and encourage students' all-round development.

(3) Novel knowledge and new tools appearing are recommended to be introduced, which can better meet the requirements of new engineering disciplines' development, making the entire professional curriculum system more systematic and complete.

(4) When practice link is slightly inadequate and part of contents are still at the theoretical level, students always lack soft skills related to engineering practice, such as communication, teamwork, and leadership. Ability training can appropriately add relevant content to better support students' future engineering practice work.

(5) The existence of the paradox of "labor shortage" and "difficult job hunting" has put higher education into thinking. The evaluation of the quality of talent cultivation is vital. Various evaluation indicators can promote the improvement of students' comprehensive quality and plays a criterion role in the advancement of talent.

Acknowledgements – This work was supported by the State Key Laboratory of HVDC, Electric Power Research Institute of China Southern Power Grid (SKLHVDC-2019-KF-16).

References

1. J. Chen and W. J. Lu, Artificial Intelligence and Talent Cultivation in New Engineering: A Major Turn, *Research in Higher Engineering Education*, **6**, pp. 18–23, 2017.
2. X. Xu, Evolution Path of New Engineering Education from the Perspective of Body of Knowledge, *Zhejiang University, School of Public Administration*, **3**, 2019.
3. X. D. Yu, H. Jia and G. Li, Design for Teaching Project of "Answer My Question" with Process Evaluation and Double-blind Peer Review. *Proceedings of the CSU-EPSA*, **31**(2), pp. 144–150, 2019.
4. M. Blanco, C. Gonzalez, A. Sanchez-Lite and M. A. Sebastian, A Practical Evaluation of a Collaborative Learning Method for Engineering Project Subjects, *IEEE Access*, **5**(193), pp. 63–72, 2017.
5. V. Krishnamoorthy, B. Appasamy and C. Scaffidi, Using Intelligent Tutors to Teach Students How APIs Are Used for Software Engineering in Practice, *IEEE Transactions on Education*, **56**(3), pp. 355–363, 2013.

6. Gu Peihua, Thoughts on the Development and Deepening of the Construction of New Engineering Courses, *China University Teaching*, **9**, pp. 10–14, 2019.
7. M. Ye, H. B. Kong and W. Zhang, New Engineering: From Idea to Action, *Higher Engineering Education Research*, **1**, pp. 24–31, 2018.
8. Lin Jian, Future-oriented Construction of New Engineering in China, *Tsinghua University Education Research*, **2**(38), pp. 26–35, 2017.
9. Lin Jian, Deeply and solidly promote the construction and implementation of a new engineering research and practice project, *Higher Engineering Education Research*, **5**, pp. 18–31, 2017.
10. D. H. Zhong, Connotation and Action of New Engineering Construction, *Higher Engineering Education Research*, **3**, pp. 1–6 2017.
11. S. Yuan and F. He, Development strategy of Harvard University of Technology and its enlightenment on the construction of new engineering disciplines, *Higher Engineering Education Research*, **2**, pp. 67–70,.
12. T. H. Hu, STEAM and Its Enlightenment on the Construction of New Engineering Courses, *Research of Higher Engineering Education*, **1**, pp. 118–124, 2018.
13. Ye Min, Kong Hanbing and Xu Xing, Discussion on the Practice Path of New Engineering: Construction of CDIO Conversion Platform Based on Grounded Theory, *Higher Engineering Education Research*, **4**, pp. 11–17, 2018.
14. K. Meagan and R. Denton, Factors Influencing Engineering Identity Development of Latinx Students, *IEEE Transactions on Education*, **10**, pp. 173–180, 2019.
15. P. Shekhar and M. Borrego, After the Workshop: A Case Study of Post-Workshop Implementation of Active Learning in an Electrical Engineering Course, *IEEE Transactions on Education*, **60**(1), pp. 1–7, 2017.
16. L. Fan and J. Y. Li, Research on the Co-construction and Co-management Mechanism of Multi-sector Collaborative Industry Colleges from the Perspective of New Engineering Science, *Education Modernization*, **5**(1), pp. 129–131, 143, 2018.
17. A. H. Wu, Y. F. Hou, Q. B. Yang and J. Hao, Speed up the development and construction of new engineering disciplines and actively adapt to and lead the new economy, *Research in Higher Engineering Education*, **1**, pp. 1–9, 2017.
18. D. Guo, Research on the Path of Cultivating Students' Core Competence under the Background of New Engineering, *Xue Weekly*, **8**, pp. 13–14, 2019.
19. L. Wang, Y. Li, Z. Wang, S. Shu, Y. Zhang and Y. Wu, Improved English Immersion Teaching Methods for the Course of Power Electronics for Energy Storage System in China, *IEEE Access*, **6**(506), pp. 83–92, 2018.
20. Q. F. Tong and J. M. Chen, Interdisciplinary development is a new growth point of ''double first-class'' construction, *China Higher Education*, **10**, pp. 42–43, 2018.
21. X. Y. Kong, L. Q. Bai and Q. A. Hu, Day-ahead optimal scheduling method for grid-connected microgrid based on energy storage control strategy. *J. Mod. Power Syst, Clean Energy*, **4**(4), pp. 648–658, 2016.

Xiangyu Kong received the BS, and PhD degrees in electrical engineering from Tianjin University, Tianjin, China, in 2001 and 2007 respectively. His research interests include smart grids, new energy, and power system analysis and control.

Wenqi Lu received the BE degree and currently pursuing the MS degree in electrical engineering at the School of Electrical Automation and Information Engineering at Tianjin University. Her research interests include smart grids, renewable enrgy and power system analyze.

Qi Guo received the BS and PhD degrees in electrical engineering from Tsinghua University, Beijing, China, in 2000 and 2006 respectively. His research interests include AC/DC large scale power system operational analysis and control, HVDC control and protection simulation.

Yihua Zhu received the BS and MS degrees in electrical engineering from Huazhong University of Science and Technology, Wuhan, China, in 2010 and 2013 respectively. His research interests include AC/DC large scale power system operational analysis and control, power system security and stability control.