In-Depth Reform and Practice of Theory-Practice Integration in Core Curriculum of Electrical Majors in New Engineering and Technical Disciplines

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***Abstract*—By studying the international mainstream advanced engineering education concepts and modes for the undergraduate training of top talents, this article explores and proposes a research teaching reform that integrates theory and practice in the core course of electrical majors. Relying on the course of "Analog Electronic Technology Fundamentals", a research-based project-driven class teaching integrated with training and competition was carried out. Through 7 rounds of teaching for 5 years, positive results have been achieved, verifying its radiation and promotion effects in terms of teaching mode and implementation measures.**

***Index Terms*—Top talent cultivation, analog electronics technology, project-driven, integration of theory and practice**

I. Introduction

According to the outline of national medium- and long-term education reform and development plan (2010-2020) in China, the Ministry of Education, together with the Organization Department of the CPC (the Communist Party of China) Central Committee and the Ministry of Finance, launched the "Experimental Plan for Training Top Students in Basic Disciplines" in 2009. Following the "211 Project" and "985 Project", in 2015, the state put forward the major strategy of "Double First-Class" construction. As the core task, it is a new mission to cultivate top-notch innovative talents. With a new round of scientific and technological revolution and industrial change, the Ministry of Education has actively promoted the construction of "New Engineering" since 2017. For colleges and universities, New Engineering refers to both the emerging engineering majors and the upgrading and transformation of the traditional engineering majors. Relying on the updated concept and mode, the goal of higher quality of personnel training can be achieved. Professor Xie Heping, the president of Sichuan University and academician of the Chinese Academy of Engineering, pointed out that to improve the quality of talent training, the most important thing is to start from the classroom and further promote the classroom teaching reform in an all-round way [1], [2]. For more than ten years, Sichuan University has explored and implemented classroom teaching reform of "inquiry-based small class", which encouraged teachers to carry out heuristic teaching, critical discussion, and non-standard answer examination in classroom teaching. It also truly guided students to study and explore actively with the reform of education and teaching mode. The above work has been highly appreciated by the industry and won the national special award for teaching achievements in 2018. On February 20, 2020, the Ministry of Education issued the No.1 document "Year 2020 Key Work Points of The Department of Higher Education of The Ministry of Education", which explicitly puts forward to carry out the first-class curriculum construction in an all-round way, promote the "Classroom Revolution" to promote students actively learn, releases their potentials, and develop in an all-round way, and creates a "Golden Course" of high-level, innovative, and challenging. It also puts forward to the further implementation of "The Experimental Plan for Training Top Students in Basic Subjects 2.0". A series of measures reflect the state's emphasis on the cultivation of top-notch talents and set a new benchmark for undergraduate course teaching.

Undergraduate education, which is the main body of higher education, plays a central role in the structural system of higher education and plays a vital role in the cultivation of top-notch talents. At the same time, the construction of automation and other traditional engineering undergraduate specialty is an important task in the construction of New Engineering. Furthermore, teaching reform of its major core basic course is bound to become the top priority. In general, the core basic course mainly focuses on imparting basic knowledge points, but there are still deficiencies in the cultivation of multiple abilities such as knowledge system, scientific research and innovation, and solving complex engineering problems. Focusing on the cultivation of top-notch talents, this paper summarizes the teaching reform and five-year practice of the core basic course "analog electronic technology". The core of this teaching mode is to introduce the theory teaching into the laboratory and establish a trinity teaching mode of "Teaching, Experiment, Practice". This work has

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achieved a breakthrough in the traditional classroom teaching of the theoretical course and constructed a new research teaching mode of core basic course for electrical majors.

II. THE ANALYSIS OF THE CHARACTERISTICS AND PROBLEMS OF THE CURRICULUM

For the cultivation of top-notch talents, compared with the engineering undergraduate education in foreign high-level universities, domestic engineering undergraduate teaching design, especially for the lower grade undergraduates, generally lacks systematic training of scientific research. Although there are many opportunities for junior undergraduates to participate in scientific and technological innovation practice projects through the mentoring system and academic competitions at all levels in the research university where the authors work, many students often feel that it is difficult to start, lack confidence, and even lose interest in scientific research due to the lack of systematic training in the early stage. Therefore, for lower-grade undergraduates, relying on the core basic course, to carry out systematic innovative practice teaching will have a crucial and far-reaching impact on the cultivation of top-notch talents.

Throughout the teaching of electrical basic core courses in domestic colleges and universities, taking the course of “Fundamentals of analog electronic technology" as an example, the teaching status and problems are mainly reflected in the following aspects: emphasize on theory over practice, focus on imparting knowledge, and the lack of systematic practice.

A. Emphasize on Theory Over Practice

The traditional teaching mode often separates the theory course from the experiment, and the experimental content is designed around the teaching knowledge points. The majority of basic confirmatory experiments show a state of emphasizing theory and neglecting to practice on the whole. As a course with equal emphasis on theory and practice, it should carry out teaching continuously and integrate theory courses, experiments, and innovative practice training. However, few efforts have achieved remarkable results.

B. Focus on Imparting Knowledge

Even if there was a results-oriented teaching design, it lacks in-depth innovation training for students in the teaching process, resulting in insufficient cultivation of undergraduates' ability.

At present, teachers in most courses mainly list the knowledge points, and the teaching methods are inclined to the output of knowledge, which weakens the responsibilities of teachers. Some courses are learning-result oriented and carry out the corresponding teaching design, but they often lack systematic teaching activities for the cultivation of students' professional knowledge, interpersonal communication, and team cooperation ability, which is not conducive to the cultivation of undergraduates' comprehensive ability such as innovation and practice.

The commonly used examination-based assessment method also focuses students' attention on the theoretical knowledge and partial skills of the course, which makes them unable to form a complete understanding of what they have learned, apply knowledge flexibly, analyze, and solve practical problems. When encountering a specific project, they are often unable to conceive, design, and implement it quickly and effectively. The abilities needed to solve complex engineering problems are insufficient.

C. The Lack of Systematic Practice

In the continuous promotion and application of research-based teaching mode, most courses focus on the discussion of problems and methods, and lack continuous and effective practice teaching.

At the beginning of November 2014, the authors of this paper had the honor to participate in the "small class teaching experience exchange meeting" held by Peking University. We found that the five small-class courses in the school of information science and technology of Peking University have realized seminar teaching, but the practice of innovative projects is rarely mentioned. However, for undergraduates, the understanding and mastery of knowledge in a course is the foundation; flexible application is the process; ability improvement is the goal. Small-class seminar teaching undoubtedly strengthens students' understanding of knowledge, but course experiment is conducive to the flexible application of knowledge points, and innovative project practice can effectively improve students' comprehensive ability. Therefore, it is necessary to realize the integration of classroom teaching, experiment and practice. Explore sustainable and effective teaching mode has become the focus and difficulty of the research.

III. NEW IDEAS OF CURRICULUM TEACHING

Benjamin Bloom, an American psychologist, and educator proposed Bloom's thinking model in the 1950s [3]. Through his taxonomic thought, he distinguished six levels of human thinking complexity: memorization, comprehension, application, analysis, synthesis, and evaluation. In 2001, an American research team revised Bloom's knowledge classification model which affected two generations of Americans, and they divided the teaching objectives into six levels: memorization, comprehension, application, analysis, evaluation, and innovation [4]. Memory and understanding belong to shallow learning. Application, analysis, evaluation, and innovation complete the transfer of existing knowledge. They realize judgment and decision-making, and solve new problems, which is why they belong to deep learning [5]. At present, Bloom's Taxonomy model has been widely recognized and applied in the field of global education [6], [7].

According to Bloom's Taxonomy model, the traditional undergraduate classroom teaching emphasizes the memorization and understanding of knowledge points, which cannot meet the need of top-notch talent training [8]. Therefore, as shown in Fig. 1, this paper proposed the "Teaching, Experiment, Practice" course teaching mode. It integrates course, training, and competition. Classroom teaching and course experiments focus on the level of memorization and understanding; comprehensive project practice focuses on the level of application, analysis, and evaluation; and discipline competition and other related scientific research activities are oriented to a higher level of innovation.

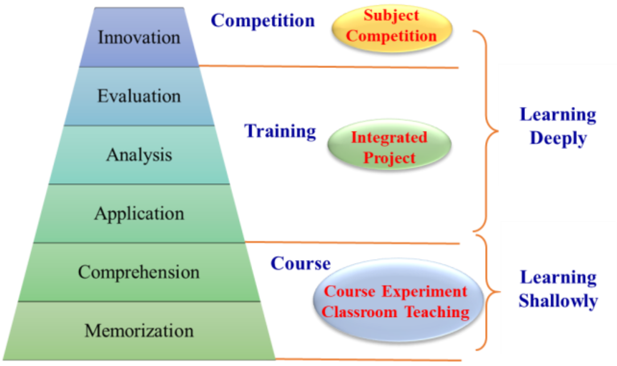

Figure 1. Teaching mode of theory-practice integration of "course training competition" based on Bloom model.

In the above mode, innovative practice teaching for lower grade undergraduates should be carried out under the guidance of teachers, or in a way similar to research-based learning. The teaching process should include all the key stages of scientific research so that students can exercise their scientific research thinking and learn innovative methods. Therefore, its essence does not lie in scientific research achievements, but it is relying on its realization of a systematic practice teaching process to cultivate students' comprehensive quality such as self-learning, scientific thinking, innovative practice, communication, and teamwork.

On the other hand, in recent years, the outcomes-based education (OBE) model has gained more and more attention in the world for its effectiveness and progressiveness [9]–[11]. OBE advocates "student-centered", focusing on what abilities students acquire and what they can do after education [12], [13]. It requires that the corresponding educational activities, educational process, and curriculum design should be carried out around the realization of the expected learning results [14]. Teachers should pay attention to the construction of an educational soft environment, and strengthen the interaction between teachers and students [15]. Funded by the national scholarship committee, the first author of this paper went to the City University of New York as a visiting scholar in 2012. During the visit, the first author participated in the work of guiding undergraduates with Professor Xiao Jizhong. Based on the expected learning results, the project-driven OBE teaching mode is designed and implemented. Driven by the task of the project, relying on the teacher's laboratory environment and resources, a group of students cooperated to carry out self-learning and hands-on practice. Under the regular guidance of teachers, the project of "small UAV laser ranging" was efficiently completed.

Built upon the above work, this paper takes the OBE engineering education mode as the traction, firstly proposed the idea of "project-driven course training competition" research teaching curriculum reform to integrate the theory and practice; secondly, carries out multiple practices in the core basic electrical course "Fundamentals of analog electronic technology". The main idea is to take the learning results as guidance, comprehensively sort out the knowledge points of the theoretical course, take the students as the center, design the comprehensive training project, and construct the process assessment method according to the project management process.

IV. The Implementation of Curriculum Reform

The American scholar and well-known learning expert Edgar Dale first discovered and proposed the learning pyramid in 1946 [16]. Later, the national training laboratory in Maine of the United States conducted a study to show the average retention rate of learning after two weeks of using different learning methods [17], [18]. As shown in Fig. 2, according to the learning pyramid model, the first "listening" method at the top level is the most common teaching method, but the learning effect is the worst. After two weeks, only 5% of the learning content can be remembered. Secondly, reading, audio-visual (e.g. sound and picture), and demonstration can reach only a 10% - 30% average retention rate of learning. The average retention rate of learning in discussion, practice, and teaching-to-others can reach 50% - 90%. Edgar Dale’s research shows that several traditional learning methods have learning effects of less than 30% and they belong to individual passive learning, which can only achieve the shallow effect of learning; while those with learning effects more than 50% belong to interactive team learning and active participatory learning, which can achieve the deep effect of learning [19].

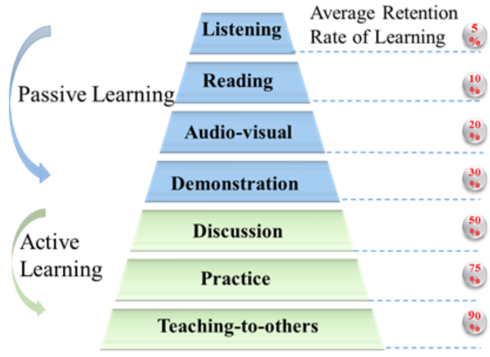

Figure 2. The learning pyramid model.

Inspired by the learning pyramid model, the teaching reform of "Fundamentals of analog electronic technology" highlights the student-centered approach and focuses on cultivating students' self-learning ability. Combined with the professional background of the students, relying on the teaching objectives and contents, we design an interdisciplinary innovation training project, and deeply practice the project-driven small-class teaching of "theory course into the laboratory". As shown in Fig. 3, the training project integrates the mainstream technology of analog electronic technology, digital electronic technology, embedded system, and other industries,

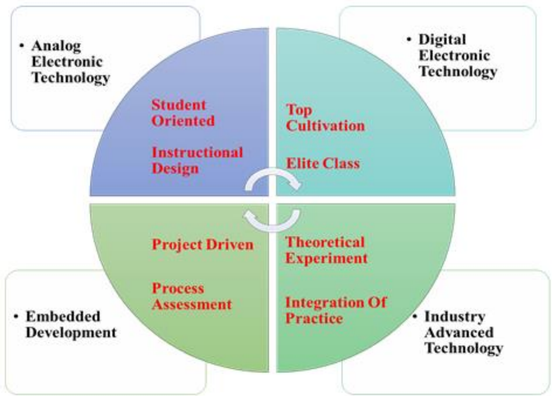

Figure 3. Overall implementation of teaching reform.

A. Process-based Course Teaching and Assessment

In the course teaching, we should focus on the students' learning process, cancel the final examination, and carry out the course teaching and assessment based on the process. As shown in Fig. 4, the teaching content mainly includes classroom teaching, the basic experiment of analog circuits, the comprehensive project, and other related teaching links. To meet the need of top-notch talent training of automation majors in Higher Polytechnic, bilingual basic experiments are specially designed [20]. The corresponding assessment contents mainly include classroom quiz (open book), homework, the basic experimental operation [21], basic experimental report, as well as defense and report of project opening, mid-term and final questions, especially focusing on the completion of physical objects. To achieve all-round training, it emphasizes the learning process and the daily accumulation of students [22], including face-to-face, network, or other ways of communication and discussion between teachers and students, attendance of open laboratories, and public service work undertaken by the students. In addition, after class, each student is required to complete a summary of "mind wandering" as the main basis for the continuous improvement of teachers' curriculum.

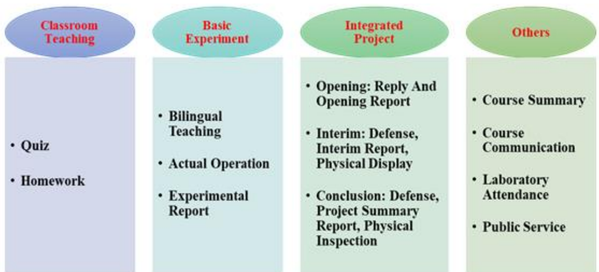

Figure 4. Course process teaching and assessment.

B. Project-driven System Practice Teaching

In the autumn semester of 2015, the teaching objects of the course "Fundamentals of analog electronic technology" are 18 junior undergraduates with the major of "Biomedical Engineering". The course aims to take this as a pilot project and start the prelude of small class "project-driven" teaching reform. At this time, China's large and medium-sized cities are repeatedly affected by haze, the air is mixed with many PM2.5 and other pollution particles, and the visibility is low, which seriously affects human health. To reduce the inhalation of harmful substances, many people choose to wear masks for prevention, but there are many brands of masks on the market, with uneven quality, and the price of foreign brands is quite high. Because of this important social demand, the first author, as the person in charge of the electrical and electronic innovation base for undergraduates of Beihang University, analyzes the characteristics of current undergraduates based on the guiding experience of scientific and technological practice activities of undergraduates in recent ten years and designs the innovative training project "intelligent anti-haze mask" in combination with the professional background of biomedical engineering. The project requires students to design an anti-haze mask that can be customized according to face and realize intelligent functions such as wireless air quality monitoring. It integrates analog circuits, digital circuits, embedded systems, 3D scanning and printing, ergonomics, and other mainstream technologies in the industry. The course project was carried out in groups of 3-4 students in each group and the students volunteered to form groups. Under the guidance of teachers and teaching assistants, the students in each group completed various tasks according to the time node. Supported by the laboratory of innovation base of electrical and electronic teaching experiment center, the project-driven teaching of this course was carried out smoothly.

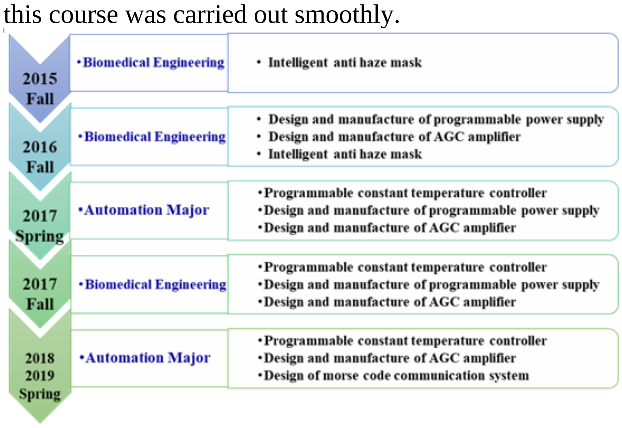

Figure. 5. Five-year practice of "project-driven" curriculum reform.

In many rounds of practice, to deepen the implementation of "student-centered" teaching and learning, the author team insists on carrying out collective lesson preparation and other teaching activities, according to the feedback of students, modify the teaching plan, and continuously improving the curriculum. According to the professional background of the teaching objects, the authors timely adjust the content and difficulty of the theory course and practice link, to achieve better teaching effect. According to project development and student feedback, the authors improve the content of the comprehensive project. For example, considering that the "intelligent anti-haze mask" project is biased towards embedded system development, 3D design, and printing content, and that the content of analog circuit design, production, and debugging is less, after two rounds of operation, the project is canceled and new project content such as constant temperature controller is added. In the past five years, the implementation of each round of training projects is shown in Fig. 5.

To further stimulate the enthusiasm of students' autonomous learning, this course is closely combined with the subject competition, and excellent students are selected from the students in a class to participate in the national/Beijing College Students' electronic design competition and other scientific and technological innovation practice activities, to build a multi-dimensional teaching mode of in-class extracurricular "class training competition".

C. Multi Round Practice Results

In the past five years, the teaching reform of "Fundamentals of analog electronic technology" has been carried out continuously. Seven rounds of practice have been carried out in automation major and biomedical engineering major (College of biological and medical engineering, BeiHang University), covering 342 students. All the students have completed the course learning, basic experiments, project production, and summary report. Fig. 6 illustrates some students' works.

Figure 6. Some students' works.

Through the feedback of students, the teaching effect of the course can be seen. In the student evaluation of teaching at Beijing University of Aeronautics and Astronautics in 2016, this course ranked first among 213 courses. In addition, the learning experience of several students is shown in Table I. It shows that the ability of undergraduates to integrate theory with practice, flexibly apply professional knowledge, innovate practice, communication. and teamwork, especially autonomous learning, has been comprehensively improved.

TABLE I. FEEDBACK FROM STUDENTS

Student Information	Comments
A student majoring in automation (now a graduate student at Georgia Tech)	This course is the first time that I feel that I am learning things, thinking, and using my brain to do work that needs wisdom, rather than doing manual work as a porter. To cope with the examination and getting good results, I lost too much in the University. So really thanks to the teacher for giving us such an opportunity. From the excitement at the beginning of the course to the depression and tension after entering the project, to the joy of completing the project, all I wanted to say was thanks.
A student majoring in Biomedical Engineering	-Through the requirements at the beginning and the end of a project, we have accumulated experience of comprehensive experiment and graduation design as a senior student. At the same time, this project also makes us fully understand the process of product design, and the whole process greatly improves our self-learning ability. -After this semester's study and practice, I realized the great benefits of actually doing a project. We have a deeper understanding of the hardware design and the function of each module. At the same time, we have improved our hands-on ability, and deeply realized the importance of teamwork and the fun of mutual discussion.
A student majoring in automation (now a graduate student at the University of Texas at Austin)	Before I knew it, a semester of analog electronics class ended. There was no intense review during the examination period. Its special scoring method was destined to leave a heavy mark in my four years of college life. At the end of the semester, looking back on the whole semester, we have gained the experience of how to form a team and how to work together.
A student majoring in automation (now a graduate student at Beihang University)	This is the end of a semester's module electronics class. I still can't give up when I think back to the days when I spent all night in the laboratory. Many things happened to me and my teammates throughout the course period: from didn't knowing each other to cooperating tacitly, from being unfamiliar to familiar with laboratory equipment, from reading circuit diagrams to designing circuits, from designing circuits to connecting real objects, and then to welding and joint debugging of circuits. I learned a lot in one semester. It's true to say that "if you get something on paper, you'll feel shallow, and you'll never fully know something unless you practice it.". I was most impressed, enriched, and fruitful in Shahe campus when I struggled into late night with the board in the lab. I'm glad that I didn't give up such good resources because I was afraid that my score might be very low. I'm also very lucky to meet three super cute and capable teammates. The time we worked together for the same goal is unforgettable.
A student majoring in Biomedical Engineering (exchange student from Beijing Institute of fashion, Beijing University of Aeronautics and Astronautics)	What surprised me most this time was that I saw the infinite possibility of integrating different disciplines. I took a double degree in fashion design and engineering, but I didn't expect to be able to combine mold and electronics. When I found that 3D printing materials were relatively hard, I directly used clothing to make more comfortable masks, which also improved my second-degree skills. The 3D scanning and printing technology in the experimental class also fascinates me. I think the combination of 3D technology and clothing can also result in innovation and will continue to explore in the future.

Some students admitted that they had invested at least 200 class hours in the 64-class hour course. Although they worked hard, they gained more. In 2019, a student majoring in biomedical engineering happily and excitedly sent a "good news" to the teacher of the author's team: in the "Moon Palace No.1" project, the AGC amplifier circuit practiced in the course has solved a difficult problem that has plagued the project for a long time and the student is deeply pleased to apply what he has learned. In addition, through the course teaching reform, outstanding undergraduates have come to the fore and won many awards such as the first prize of Beijing in the National Undergraduate Electronic Design Competition and other discipline competitions. The team teachers guide undergraduates to publish nearly 10 academic papers and teaching research papers. Related work has won the second prize of CAA (Chinese Association of Automation) higher education teaching achievement and the first prize of Beijing University of Aeronautics and Astronautics teaching achievement. There are 10 awards for teaching achievements at all levels. It is worth mentioning that this research is supported by the general project (2015A31) "teaching reform of integrating theory course and practice of analog electronic technology under CDIO-OBE engineering education mode" of professional education and teaching reform research project of automation professional teaching steering committee of Ministry of Education in 2015. In the national automation education academic annual meeting in August 2019, our relevant work was unanimously recognized by experts and won the excellent closing award. Only four of 31 national closing projects won this honor.

V. Thoughts on the Reform of Curriculum Teaching

Through five years of practice, the teaching reform of this course has realized the deep integration of electronic technology theory course, basic experiment, innovative practice training, and subject competition of the core course of electricity. The combined teaching of theory and practice encourages students to take the initiative to practice and improve their comprehensive ability. As far as the author's team teachers are concerned, the work has been continuously and steadily promoted, mainly due to the following factors.

A. Reform Mode

Teaching reform of this course aims at the cultivation of top-notch talents and carries out small-class teaching. Generally, there are no more than 50 students, and the best scale is about 30 students. In the design of a comprehensive training project, we should consider the needs of the industry, teaching content and professional background, encourage and cultivate students' ability of independent innovation and practice, and do not impose too many constraints on the implementation scheme (hardware platform, device selection, etc.) and some functional indicators, to encourage the initiative of students. The practice has proved that students can take the initiative to think and explore the implementation ideas, which are of great benefit to the cultivation of the ability to solve complex engineering problems. In addition, the number of projects should not be too many, the same project should be completed by multiple groups, which are conducive to the comparative analysis of the practical effect.

On the other hand, a team of teachers have been adhering to the belief of teaching and educating people, moral education, in class and out of class with a line, adhere to the front-line teaching every detail of their own work. For example, after class teaching, we can answer questions on the Internet regardless of time; in the process of guiding the project, when we meet confused students, we can have a chat and guide them in their outlook on life and values; we encourage aspiring students to continue their further study and are willing to write letters of recommendation for students who are going abroad to study for postgraduate. The above practice has played a very good word-of-mouth effect, encouraged more diligent excellent students register our courses, and promoted the teaching effect.

B. Teacher Team

The teaching team for this course is composed of senior theoretical and experimental lecturers with a solid theoretical foundation and rich practical teaching experience. It is a stable young and middle-aged backbone teaching team. Team teachers continue the practice of "mentoring" introduced by the older generation of teachers, work together, complete the doubled workload of curriculum reform, and steadily promote the tasks of teaching reform. In addition, senior students with certain scientific and technological practice experience trained in the base are also arranged to undertake the teaching assistant work and guide each group to carry out the project practice. Some of the teaching students are willing to join the teaching assistant team after studying, which promotes the virtuous circle of teaching reform.

C. Base Support

The laboratory of innovation base of electrotechnics and electronics teaching experimental center of Beijing University of Aeronautics and Astronautics has built an open platform for undergraduate innovation and practice. It is equipped with a high-performance multi-channel digital oscilloscope/signal generator, regulated power supply, multimeter, other sets of electronic measuring instruments, 3D scanning/printing platform, printed circuit board plate making machine and other equipment. It has already been used safely and stably for many years with the opening of remote video and electronic attendance. The laboratory is open to all students' needs, fully supporting the teaching reform of this course and the scientific and technological innovation practice of undergraduates.

At present, laboratory safety management is the focus and difficulty of university work, especially for open laboratory management. Therefore, in the process of carrying out the project, the implementation of the multi-level management system, by the team leader to manage the team members, the class representative to manage the team leader, the class representative is directly responsible for teachers, to achieve the responsibility to people, hierarchical management.

D. Project Support

In the process of continuous development of the teaching reform, it has been recognized and supported by many parties. In addition to the general project (2015A31) funded by the Ministry of Education automation professional teaching steering committee in 2015, it has also been approved as the research project of 2017 top students training experimental plan of basic disciplines of Higher Institute of technology of Beijing University of Aeronautics and Astronautics, and the research project of 2017 top students training experimental plan of basic disciplines of Higher Institute of technology of Beijing University of Aeronautics and Astronautics. It is supported by five teaching and research projects, such as the teaching reform project of "Fundamentals of analog electronic technology" of Beijing University of Aeronautics and Astronautics. In addition, because of the outstanding achievements of the course in teaching, the relevant colleges allocated the corresponding course construction funds for students' consumables expenditure in each round of teaching. The above measures strongly supported the continuous development of the teaching reform.

VI. Conclusion

Based on the OBE engineering education model and the analysis of the similar achievements of universities and research institutions domestic and abroad, this paper puts forward and practices the research-based teaching reform of the electrical core course "Fundamentals of analog electronic technology". This work has been carried out continuously for five years, completed seven rounds of teaching operation, covering more than 300 students, and achieved gratifying results. Finally, a new mode of research-based teaching of electrical core courses is formed, which completely breaks the traditional classroom teaching of theoretical courses. Aiming at the undergraduate training of top-notch talents, in the "Double First-Class" course under the background of New Engineering, this work has positive radiation and promotion value in many aspects, such as teaching concept, teaching mode, and implementation measures.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Jin Xiao is mainly responsible for the overall design of the teaching reform project and the guidance of the undergraduate innovative practice project. Yao Tang is mainly involved in the overall design of the teaching reform project and lecturing analog electronic technology theory course. Xiaoguang Hu is mainly involved in the overall design of the teaching reform project and lecturing digital electronic technology theory course. Tianyao Zhang is mainly responsible for teaching and guiding undergraduates to practice projects.

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