Deeply Blended Teaching and Learning in the Course "Principles of Electric Circuits" Based on MOOC

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***Abstract*—This paper proposed an online and offline deeply blended teaching and learning mode in the course "Principles of Electric Circuits" in Tsinghua University since 2013. Students are required to preview all contents by watching videos in MOOC, profound discussion will be hold in class time, including questions met in preview, comprehensive problems, extensions of principles application and portable experiments. Firstly, general pedagogical design of this innovative mode was introduced in detail, and the lectures of "sinusoidal steady state analysis" set as an example. Secondly, the assessment policy of the course was designed including both process and summative evaluation, which aims to stimulate the continuous effort of the student and evaluate their all-sided growth in the course. Then verified course improvement compared with parallel classes of the same course was introduced, including examination grades, questionnaire feedback and following performance of the students. Finally, several key points and our corresponding measures which are critical for the success of this teaching and learning mode were explained.**

Keywords—blended teaching and learning, portal experiment, process assessment

I. INTRODUCTION

With the rapid development of MOOC around the world and the emergence of a large number of high-quality and cheap online education resources, blended teaching and learning will become the inevitable trend of future education. On the one hand, the blended teaching mode with deep integration of online and offline gives full play to the advantages of flexible online learning time and rich resources. On the other hand, personalized problems can be timely solved through offline face-to-face teaching. In-depth discussions between teachers and students and peer learning make the teaching and learning process warmer. Our course, Principles of Electric Circuits, as the first MOOC in engineering discipline in China, had been released on both edX and xuetangX since Oct., 2013[1][2]. About 50000 learners have participated our MOOC from more than 160 countries and regions by now. From the very beginning of its online release, we hoped this novel resource of learning can be a great help of our course in campus. Its characteristic of fragmentation is highly suitable for self-learning in preview, consequently more creative activities can be carried out in class time.

Tsinghua University stays on the top level in many engineering disciplines in China, so does in electrical engineering. The course "Principles of Electric Circuits" plays a very important role in talent cultivation, it is the first fundamental course of the specialties related to electricity. With the traditional teaching and learning mode, that is, lectures dominated by teaching in a large classroom, demand from a small amount of students who want to challenge themselves with in-depth theoretical inquiry or complex experiment can not be satisfied. These students with strong internal driven force are most valuable in talent cultivation, teachers are responsible to provide them a platform to tap their potentials to the maximum extent.

We developed a deeply online and offline blended teaching and learning mode and realized by flipped classroom since spring semester in 2014[3][4]. General pedagogical design for all 29 lectures was proposed in the paper, and three lectures covering sinusoidal steady state analysis were introduced in detail to express the realization of the design. Trinity idea was followed, that is, value, ability and knowledge (VAK).

Detailed pedagogical design of the blended teaching mode was introduced in the paper firstly, including preview, discussion in class and review. VAK realization in the whole teaching and learning process was described. Assessment policy was designed to match the blended teaching mode to encourage the students to take each step seriously. Then, the effectiveness of this teaching mode is proved by comparing with the midterm and final test scores of parallel classes, students' feedback from questionnaires, and students' performance in follow-up courses and scientific research activities. Finally, several key problems encountered by the authors in this teaching mode and their solutions are described, including experiments design, extracurricular time control, balance of course challenge and students' sense of achievement, etc.

II. PEDAGOGICAL DESIGN OF BLENDED MODE

The pedagogical design of the course "Principles of Electric Circuits" applying deeply blended mode mainly includes three parts: pre-class, in-class and after-class, covering the whole process of teaching and learning. The design sticks to our university's educational idea in new era, which is called by "trinity", that is, value shaping, ability training and knowledge transferring, and these are also three-level objects of our course. The pedagogical design result is shown in Figure 1. Obviously, each kind of activity contributes to at least one object, and each object is supported by several activities, which will be explained in detail in the following sections.

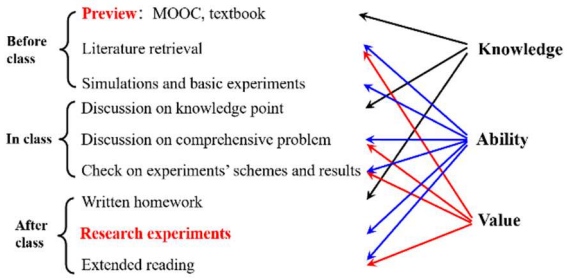


Fig. 1 Pedagogical design of blended teaching and learning mode

A. Preview before Lectures

Preview is an important prerequisite for the successful implementation of class discussion, so it is necessary for teachers to carefully design the preview content of each lecture, and to collect appropriate and rich teaching resources to support.

The preview content should include:

(1) videos on basic concepts which can highlight the key points, however it is better not to use the recorded video of actual class lectures. There are two reasons. Firstly, it takes too long for students to preview; Secondly, teachers need to prepare many new contents in class different from those shown in videos to avoid repetition, which not only increases their workload but also make the course harder than it ought to be. Therefore, MOOC characterized by fragmentation is most suitable for pre-class preview of blended teaching and learning.

(2) textbook of high quality. The integrity and rigorous logic of textbook can help students accurately establish knowledge system, rather than learning a bunch of fragments. Of course, it is also one of the main tasks of discussion in the classes to reorganize knowledge fragments into interconnected wholes.

(3) literature retrieval for some chapters. This design aims to help students understand the background of knowledge generation or the forefront of knowledge application. Simulation and basic experiments are also one of the preview contents of some chapters. Through simulations and experiments, students can understand concepts and theorems more thoroughly, and improve their ability to flexibly use the knowledge learned to solve practical problems.

During preview timely mutual feedback between students and teachers is necessary. Students should know to what extent they have understood the knowledges through exercises and other methods, and teachers should be able to know students' preview states in time for supervision.

Through the above contents, students' independent learning ability, literature review ability and hands-on ability can be effectively exercised and improved, and meanwhile, correct scientific ethics, academic norms and professional cognition can be formed unconsciously. The educational idea of trinity will be realized by the mentioned and following specific teaching activities.

A copy of detailed pre-class arrangement including the above preview contents for each class will be provided to all students, so that students can preview accordingly. Taking the first lecture of sinusoidal steady-state circuit analysis (three lectures in total) as an example, the preview arrangement (excerpt) is shown in Fig.2.

Preview Assignment of L20

1. Self-learning

Contents：Basic concepts of sinusoidal variables, phase form corresponding to sinusoidal variables
Textbook: Chapter 13.1
SPOC: Lecture 59-61

2. Key points

1) Three elements of sinusoidal variables, principle value interval of phase
2) What two sinusoidal variables can be compared in phase difference? Interval of principal values of phase difference (of the same frequency)
3) In-phase and antiphase
4) Phase relation of voltage and current of *R**L**C* elements
5) Definitions of effective and mean values of periodic signals
6) The relation between the effective value and amplitude of sinusoidal variables
7) Elements of phasor, Symbol of phasor
8) Why can we use phasors to represent sinusoidal variables? Consequently what is the range of application of phasor?
9) The correspondence between phasor and sinusoidal variable
10) The correspondence of calculation rules between phasor and sinusoidal variable
11) Two forms of complex numbers and their interconversion
12) What form is convenient for adding and subtracting complex numbers?? And for multiplying and dividing?
13) Two ways to draw a phasor diagram

3. Exercises

（1）Calculate the mean value and effective value of square wave and sawtooth wave with period T, minimum value 0 and maximum value E respectively (duty cycle of both is 50%)
（2）Exercise sets 11-5, qualitatively draw the voltage and current phasor diagram of each circuit as shown in Figure 11-5.

4. Literature Retrieval

Please search relevant literatures on each link of the power system (power generation, transmission, transformation and distribution, electricity consumption and energy storage) in groups. The data collected is required to be updated at least until the end of 2019.

Each group should prepare a 3-5 minute PPT (excluding the table of contents, the core content should not exceed 5 slides), and give a presentation in the next class. You can do a review of the development of the field, or you can do a more in-depth introduction to a certain point.

Please send the electronic version of PPT to my email address before next class: gpzhu@tsinghua.edu.cn。

Fig. 2 Preview Assignment for the First Lecture of Sinusoidal Steady State Analysis

B. Discussions during Lectures

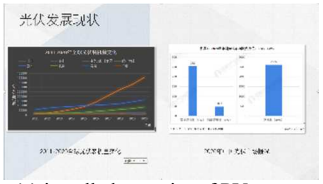
Since students have already previewed the core content of lectures by watching MOOC or reading textbooks, teachers can no longer focus on lecturing as in the traditional class, but on discussions, including discussions between teachers and students as well as between students.

Discussions in class mainly include :

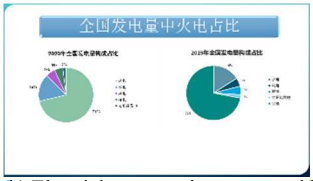
- Discussion on knowledge points. Since all knowledge points had been numbered in preview file, students can find what they cannot understand easily and raise for discussion. Students are encouraged to ask questions and answer each other. Teacher plays a role of organizer and complementor, when all students are stumped by a question, teacher will answer it.
- Discussion on comprehensive problems, especially those with specific engineering background or industry application scenario. Students can understand basic concepts and theorems more deeply, and learn how to apply them flexibly.
- Discussion on experiment's scheme or results. In the blended teaching and learning mode, the experimental

content is completely arranged by the lecturer according to the schedule of the theory class instead of by full-time experiment teacher in the lab. Instead of providing a designated experimental scheme, only the experimental objectives are proposed, and the experimental scheme will be designed by the students themselves. With the help of portable experimental equipment, students do not need to go to the designated place (laboratory) at the designated time to complete the experiments and can carry out experiments anytime and anywhere[5]. There is no doubt that this experimental mode can greatly improve the student's hands-on ability, and also bring a great challenge to students at the same time, therefore teachers need to give timely help, including discussing the experiment schemes and problems met in the experiments in the lectures, which have been proved to be effective.

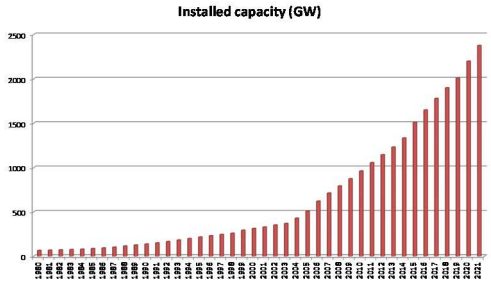
Again, taking lectures on sinusoidal steady-state circuit as an example. In the first lecture, students are required to give a presentation according to their literature research results before class, some slides and photos of their presentation are shown in Fig.3. Through this activity, students will have a comprehensive preliminary understanding of the history and current situation of China's electric power industry, which greatly inspires their professional pride and establishes a sense of responsibility.



(a) installed capacity of PV



(b) Electricity proportion generated by various resources



(c) total installed capacity in China from 1980 to 2021

Fig. 3 Presentation by Students in the Lecture

In class, some comprehensive questions are discussed, as shown in Fig.4. With the help of the special design of the appropriative classroom for blended teaching and learning, multiple students (up to about 10 students) can solve the same problem on the blackboard at the same time, so that the potential errors in their understanding can be fully exposed in a very short time, and then corrected by other students and explained by the teacher. After this process everyone is impressed with the concepts especially those he could possibly go wrong.

Fig. 4 Comprehensive Problems Discussion in the Lecture

The experimental schemes and results are also discussed in class, as shown in Fig.5. This is usually the happiest time for students, who are not afraid of exposing their problems in the experiment and are quite willing to show their experimental results to others.

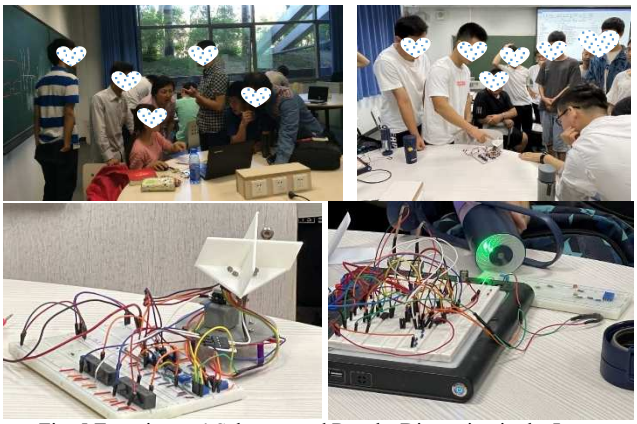


Fig. 5 Experiments' Schemes and Results Discussion in the Lecture

Typically, for a 90-minute lecture, these three parts of discussions take up about 3:2:1, but it is not a strict limit or rule. It is totally dependent on the contents of each lecture.

C. Review after Lectures

In addition to the regular written homework, after most of the lectures students are required to complete some research experiments according to the contents taught in lectures. Experiment is an important highlight of this teaching mode. Through the experiments students can not only understand the basic concepts and theorems more deeply and more accurately, but also learn that how to flexibly apply knowledge in what situations and to achieve some circuits with specific functions. Knowledge does not just stay in the books or slides. Taking sinusoidal steady-state circuit analysis as an example. After the three lectures, students are required to realize a sinusoidal waveform generator by themselves. Fig.6 shows the appearance of our portable experimental device, AD Lab, and part of an experimental report submitted by students through the online experiment platform customized by the course (RainClassroom) after completing the experiment on AD Lab. Teachers can see all students' experimental reports on their mobile phones at any time, and reports can be reviewed in the mobile phones and computers.

Fig. 6 Experiment Reports of Sinusoidal Wave Generator completed by AD Lab and Submitted in RainClassroom

The experiments that need to be completed in this course are shown in Table I, among which the highlighted experiments are those that need to submit experimental reports. For other experiments, students only need to demonstrate the experimental results to the teacher in class without writing special experimental reports. This arrangement is also to control the reasonable extracurricular time requirement of the students, so as not to affect their learning of other courses in the same semester. It is actually very important; however, many teachers often tend to ignore. If the extra class time requirements are too much, even affecting students' learning of other courses, then in the next semester less students will be willing to select this course, this teaching model will not be sustainable.

TABLE I
EXPERIMENTS REQUIRED IN BLENDED TEACHING AND LEARNING MODE

NO.	Objectives of Experiment
1	Measure the *u-i* characteristics of the resistor
2	Measure the *u-i* characteristics of the diode
3	Measure the port and transfer characteristics of MOSFET, and realize an inverter with MOSFET
4	Realize an Adder with OpAmp
5	Measure the Thevenin's equivalent circuit of the port +5V and GND of the portable device
6	Realize a small signal amplifier with MOSFET
7	Research the response of the 1st-order RC circuit excited by pulse series
8	Research the propagation delay of MOSFET inverter
9	Realize the pulse generator and triangle generator
10	Realize and improve the full-wave rectification circuit
11	Realize a sin-wave generator
12	Realize a virtual inductor by simulation
13	Open experiment of competition

Of the above experiments, the last one is the most challenging and takes the longest, taking about 6-7 weeks. The content of this experiment is completely open, and students can determine it freely. The experiment scheme is designed by students themselves. In the process of the experiment, feasibility report and mid-term report will be required to be submitted. Finally, there will be an on-site demonstration and defense, and teachers and all students will score together accordingly, and the top three groups will be awarded appropriately. According to the experience in the past nine years of this course, students in this experiment shows the strong self-study ability and creativity, not only applying a lot of knowledge learned in this course, but also learning a lot of other knowledge by themselves in order to complete the experiment. It is very important for freshman students new to electrical engineering. The setting of this link effectively exercises students' comprehensive learning ability, and trains them to face difficulties or failures positively and never give up easily, which is necessary for them to engage in more difficult professional learning in the future.

III. ASSESSMENT POLICY AND EFFECTS EVALUATION

Because of the difference between the deeply blended teaching mode and the traditional mode, so summative assessment usually adopted in the traditional teaching mode is not suitable to copy completely in blended teaching mode, which needs to be supplemented by the process evaluation[6-7], including online learning, in-class performance, after-class experiment and written homework. On the one hand, a comprehensive evaluation system can accurately assess the students' academic performance, on the other hand, it can also effectively stimulate students' learning motivation and maintain necessary investment in all aspects of teaching.

The grade composition of this course is shown in Fig.7.

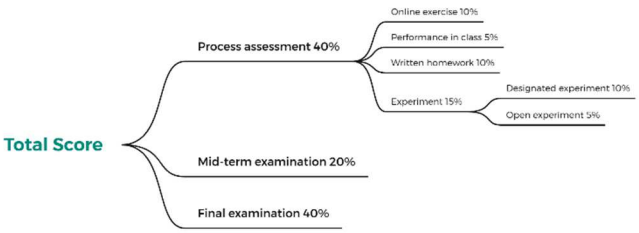


Fig. 7 Grade Policy of Blended Teaching and Learning

It can be seen in Fig.7 that process assessment accounts up to 40%.

- Online performance is assessed automatically by MOOC platform according to the accuracy rate of exercises.

- Performance in class includes two parts, one is quantitative which was counted automatically by RainClassroom (a smart tool for teaching and learning, now is widely applied in China) representing the accuracy of the students' answers during the interaction in the lectures, the other is qualitative representing the activeness and contribution to the discussion in the lecture, and it was assessed mutually by students.

- There are totally 15 times of written homework, but only top 10 scores were counted in the final score. This kind of design gives the flexibility of learning and effectively relieves students' anxiety of score.

- Experiments were highlights of this blended teaching and learning mode, so it took up the largest proportion in the process assessment. Special awards were set for the open experiment which was graded mutually onsite in the lecture according to their oral report, answering questions and physical circuit performance. According to outcomes in past nine years, interests and enthusiasm of students were highly stimulated, and about 60 prototype circuits with practical values were realized by them.

- To accurately and objectively compare the effectiveness of the blended teaching mode and the traditional teaching mode, students participating in the two teaching modes will take the mid-term and final exams of the same test paper at the same time. Statistical results over the years

showed that the average score of the class applying the blended teaching mode is about 5 to 10 (total score is 100) higher than the average score of the class with the traditional teaching mode, which proves the success of the blended teaching mode from one aspect.

Additionally, students in Tsinghua University are required to evaluate the courses they have participated every semester. Some of the evaluations on the blended teaching mode of this course are listed in Table II. These feedbacks indicate that students approve of the blended teaching mode.

TABLE II PART OF COMMENTS OF BLENDED TEACHING AND LEARNING MODE FROM STUDENTS

NO.	Comments from Students
1	Give students enough space, very free; You can learn a lot in this course.
2	Enlighten the mind! Have very strong expandability!
3	Be good at guiding students to discuss and think positively in class
4	Free to ask questions in class, the important and difficult points are prominent
5	Face-to-face communication in class, new mode, new harvest
6	Flexible, pay attention to preview, developed our good study habits.

Students who participated in the blended teaching mode also performed very well later in their undergraduate studies. According to incomplete statistics, by the end of 2021, a total of 198 students have participated in the blended teaching mode, 103 of whom have graduated. They have participated in various science and technology competitions and won more than 100 awards during the undergraduate stage, and about 50% of the students have directly entered Tsinghua University for postgraduate study. Although this cannot be attributed simply to the contribution of this course, at least it shows that this course provides a platform for these students with potential to show their talents at the initial stage of professional learning, which itself is also one of the teaching objectives of the blended teaching mode.

IV. KEY POINTS OF BLENDED TEACHING AND LEARNING

Although deeply blended teaching mode has been proved to be effective in stimulating students' interest in learning and improving their learning effectiveness, the following key issues need to be paid special attention to and properly solved to successfully implement this teaching mode.

A. Comprehensive Teaching Resources

The successful implementation of blended teaching and learning requires the support of comprehensive teaching resources, including videos for pre-class preview, special textbooks that meet the needs of blended teaching, courseware customized for classroom discussion, problem sets, portable experiment devices, etc. Since 2013, our group of this course, Principle of Electric Circuits, has successively built rich teaching resources that can support blended teaching, as shown in Fig.8. These teaching resources with high quality not only provide resources guarantee for the implementation of blended teaching in our own courses, but also provide great help for the implementation of blended teaching in domestic counterparts except the unpublished courseware.

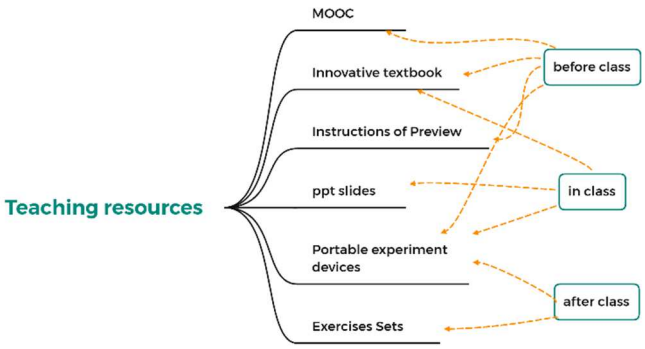


Fig. 8 Our Teaching Resources applied in Blended Teaching and Learning

B. Balance between Course Difficulty and Student Satisfaction

In recent years, The Ministry of Education of China has issued several documents [8], requiring undergraduate courses to be challenged. However, due to the high ratio of hours taken in after-class and in-class, teachers who apply the deeply blended teaching mode easily tend to focus on high challenges of course while ignoring students' satisfaction and sense of achievement, thus greatly affecting students' learning experience. Course challenges degree is definitely not the higher the better, even in the same class, when teachers design the teaching tasks, it should have appropriate flexibility, allowing students to choose according to their own actual situation. Students are expected to obtain a sense of accomplishment and good course satisfaction in the process of facing challenges and overcoming difficulties, and constantly improve their self-confidence.

C. Suitable Time Requirement outside Class

As the first professional basic course for students majoring in electricity, the course of Principles of Electric Circuits is generally taught in the second semester of freshman year. In the traditional teaching mode, the ratio of in-class and out-of-class hours is usually 1:2, while in the deeply blended teaching mode, the ratio is usually 1:3. More extracurricular time investment will undoubtedly improve students' achievement in this course, however in this semester they usually have 5 or 6 compulsory courses, such as mathematics and physics courses, too much extracurricular time requirement will probably affect the students' learning other courses, which consequently leads to the feeling of regret at the end of the semester. It should be carefully avoided while teachers make curriculum design.

V. CONCLUSIONS

The whole process of the deeply blended teaching and learning mode applied in the course, Principles of Electric Circuits, in Tsinghua university was introduced in detail in this paper, including teaching idea, overall pedagogical design, preview arrangement, in-class discussion, experiments design, grading policy and teaching resources. Special attention to this kind of teaching mode of course challenges, ratio of in-class and out-of-class hours were expounded. Students' subjective feedback and objective scores over the years show that this teaching mode is effective, which can effectively stimulate students' interest in learning, improve their hands-on ability and cultivate their innovative thinking. The relevant resources and implementation experience of this course provide valuable assistance to Chinese counterparts.

ACKNOWLEDGMENT

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