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Integrating of Creativity and Self-Study in Analog Electronic Technology Education Through Project-Based Design*

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This paper presents a method of analog electronics experimentation that increases the number and types of project-based design experiments including circuit design and system design. Students are free to choose different experiments or design innovative circuits by themselves. At the same time, the lecture content has also been tailored to add an introduction to the history and development of analog circuits, an introduction to modern analog integrated circuit chips, and electronic systems. During two years of practical teaching, questionnaire surveys were conducted, the results of which showed that the effects of approach were very good. Most students believe that the method has a good influence creativity, self-study capability, and hands-on skills. In addition, the university's teaching evaluation results prove that the reform method was indeed conducive.

Keywords: analog circuit; creativity; design projects; experimental research; innovation

1. Introduction

1.1 Background

The course of analog electronic technology is an engineering course that emphasizes practice. Therefore, in addition to study the theory of electronic components and circuits, students need to do a lot of experiments. However, students often feel that they have difficulties in learning these theories so that they are not interested in this course. Experiments not only help students understand how circuits work, but they also help them apply what they have learned in practice. In addition, the experiments can help students make innovative designs on their own, which will make them interested in this course. Therefore, experimentation is very important for this engineering course.

The experiments include basic experiments, circuit design experiments, and system design experiments. In basic experiments, students need to measure or adjust the performance of a given analog circuit so that they can understand how the circuit works. In circuit design experiments, students need to design circuits with a given function or performance. In system design experiments, students need to design practical electronic systems so that they can understand the application of the circuit in practice. Experimental methods usually include software simulation and hardware experiments. This paper introduces the experimental reform approach, which focuses on improving students' ability to innovate, self- study, and hands-on skills.

1.2 Related work

In recent years, the engineering industry has begun to focus on the lack of 'creative thinking' and innovation in graduates [1]. Design is an exercise both in creativity and coordination [2], but unfortunately, engineer's training involves little education in design, yielding instead to a rigorous tour of traditional sciences, technological theory, mathematics, and analytical methods [2]. At present, the training of design in the teaching of analog electronic technology course is also insufficient.

The experimentation related courses are listed in table 1 [3–27]. For example, reference [3] described the first course of electronics at University of California, Berkeley, which introduced topics of analog and digital signals and circuits, conversion, sensors, and energy storage on the basis of concrete design examples. To emphasize design, the course starts with the goal of designing a flashlight with several modes including variable brightness, blinking, signaling an SOS pattern, etc. Reference [6] describes an introductory analog electronics course developed in conjunction with a major curriculum revision in the Electrical and Computer Engineering department. It provides specific examples of both the in-class projects and laboratory exercises specifically designed to improve design and team based performance. Reference [10] presents a mixed-signal EEG (Electroencephalograph) interface circuit for use in first year electronics courses Circuit and System. The completed circuit involves using instrumentation amplifiers and filters for the EEG interface. Besides, Reference [19] presents several

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Table 1. Experimentation related courses

References	Course descriptions
Reference [3–5]	have both theory lectures and experiments
Reference [6–9]	have hardware experiments, and each student performs the same basic or circuit design experiments
Reference [10–16]	have hardware experiments, and each student performs the same system design experiments
Reference [17–20]	provide experimental boards for hardware experiments
Reference [21–23]	use simulation software in experiments, and each student performs the same basic or design experiments
Reference [24–27]	use the Internet for remote basic experiments, and students operate hardware circuits through computer networks

measurement experiments performed by means of the Texas Instruments Analog System Lab Kit (ASLK) PRO board. Moreover, Reference [21] describes a computer-aided approach to teaching undergraduate course in Electronics which use symbolic manipulation package MAPLE to enable the students to analyze and understand complicated circuits. Furthermore, some courses use the Internet for remote experiments, and students operate hardware circuits through computer networks. Reference [24] describes a remote laboratory for teaching analog electronics, which provides several online lab works such as multistage amplifier experiments, differential amplifier experiments, and operational amplifier experiments.

As can be seen from the above survey, students conducted the same experiments in most courses, including hardware experiments and software simulation experiments. However, the downside of these course experiments is that students cannot choose to do different experiments, or they can choose one of the experiments but cannot make innovative designs. Due to restrictions in choice, students' motivations and interests in self-study and research are reduced. In addition, because students have fewer opportunities for innovative design, they know very little about the application and development of electronic technology. As a result, the experiments in these courses are limited in developing students' creativity and self-study ability.

1.3 Contribution of this paper

The course of analog electronic technology offered by the Department of Automation, Tsinghua University, Beijing, China, includes theoretical lectures and experiments. The experiments included hardware experiments and simulation experiments using Multisim or Tina-TI as simulation software. In recent years, we have reformed these experiments in order to improve students' creativity and self-study skills as well as hands-on skills. The number of circuit design and system design experiments has increased so that students can choose one or more of them to learn, or they can design other innovative circuits themselves. In addition, in order to facilitate students' self-study and innovation, they are provided with portable experiment boards and virtual instruments. The course has proven successful in encouraging students to learn independently, research and innovation.

2. Course description

2.1 Course objectives

The goal of this course is to help students learn about semiconductor devices and commonly used analog circuits. In addition, in order to develop students' creativity, self-study skills, and hands-on skills, they also need to learn how to design simple analog circuits.

2.2 Teaching contents

The teaching contents include semiconductor devices, single-stage amplifiers, multi-stage amplifiers, operational amplifiers, feedback, application circuits with feedback, power amplifiers, as well as DC power supply. The application circuits with feedback include arithmetic circuits, filters, voltage comparators, non- sine wave oscillators, sine wave oscillators, and voltage to frequency (V-F) converters.

2.3 Experiments before reform

The experiments before reform included hardware experiments and software simulation experiments.

2.3.1 Hardware experiments

The hardware experiments consisted of three basic experiments, one circuit design experiment, and one system design experiment, as shown in Table 2.

2.3.2 Software simulation experiments

Compared with hardware experiments, software simulation has the advantage of being able to quickly design, design complex circuits, and observe device characteristics. Three kinds of software

Table 2. Hardware Experiments

Type of experiment	Experiment content
Basic experiment	Single-stage transistor amplifier Two-stage amplifier Waveform generator
Circuit design experiment	Designing amplifier with a negative feedback
System design experiment	Designing a circuit to measure amplitude of sine wave

Table 3. Software Simulation Experiments

Type of experiment	Experiment content
Measurement of the characteristics of semiconductor device	Diode Volt-Ampere characteristics BJT output characteristics FET output characteristics
Amplifier design	Designing an operational amplifier
Arithmetic circuit design	Designing a circuit to solve second order differential equation

simulation experiments were designed, as shown in Table 3.

2.4 Course reform method

2.4.1 Motivation

Although the course has simulation experiments and hardware experiments, students can neither choose experiments based on their own interests nor design innovative circuits. Therefore, students not only know little about the practical application of analog circuits, but also lack the opportunity to cultivate creativity and self-study ability. To change this situation, the number and type of circuit design and system design experiments is increased, allowing students to freely choose experiments and design their own innovative circuits. In addition, in order to help students understand how to design innovative circuits, new content has been added to the classroom teaching to introduce modern analog IC chips and actual electronic systems.

2.4.2 Reform method

Teaching methods have been reformed in three areas. Firstly, the content of classroom teaching has been changed to add the introduction of modern analog integrated circuit chips and application electronic systems, which the students are encouraged to further self-study outside the classroom. Secondly, the experimental content was improved to add many design experiments so that students could choose a design experiment or try to design an innovative circuit. Finally, the evaluation method was modified, the score of the theoretical test was reduced by 10 points, and the experimental score was increased by 10 points.

3. Contents of curriculum reformation

3.1 Classroom teaching reform

Firstly, before analyzing a circuit, its application background is introduced, so that students can better understand its design method and practical application. For example, when introducing a logarithmic amplifier, it is first introduced that a logarithmic amplifier can be used to compress a signal, such as a light intensity signal with a wide amplitude range. Then the circuit structure of the basic log amp is analyzed, and finally its shortcomings are discussed.

Secondly, the latest analog integrated circuits produced by internationally renowned semiconductor companies are also introduced. For example, the actual log amp log 104 is analyzed and explained how it improves the shortcomings of the basic log amp. After that, students are encouraged to further study the working principle and application of log104.

Finally, it introduces modern electronic systems used in various industries. It not only describes the composition of modern electronic systems, but also describes its design methods. These electronic systems include light intensity measurement systems, audio amplifier systems, human body pulse meters, air pollution monitoring systems, industrial sonic logging systems, and industrial pressure measurement systems. In addition, the latest electronic innovations displayed in the world's largest consumer electronics exhibition from 2016 to 2017, such as smart belts, smart cocktail mixers, USB charger batteries and Microsoft headwear VR, have been shown to students and inspired their learning interests and enthusiasm.

3.2 Experiments reform

Many circuit design and system design experiments were designed in order to enable students to learn and study practical application circuits. These experiments can be divided into the following two types, the first is the application of analog integrated circuits, and the second is the design of electronic systems.

Examples of the first type of experiments include: (1) performance measurement of the general-purpose operational amplifier LM358; (2) circuits for calculation integration designed with LM358 and with ACF2101 chip; (3) circuit for calculation square and square root designed with integrated analog multiplier MPY634; (4) voltage comparators designed with LM358 and with an integrated voltage comparator; (5) circuit for conversion of triangular wave to sine wave; (6) circuits for V-F conversion designed with LM358 and with LM231 chip. Some schematic or actual circuits of the above experiments are shown in Fig. 1 to Fig. 5.

Examples of the second type of experiments are as follows:

(1) sound and light controlled lamp; (2) Step Wave Generator and its application: a Step Wave Generator is designed and used to measure the output characteristics of a transistor; (3) audio amplifier including a signal preprocessing circuit with a LM358, a low-pass filter with a LM358, and a power amplifier with a LM386; (4) simple

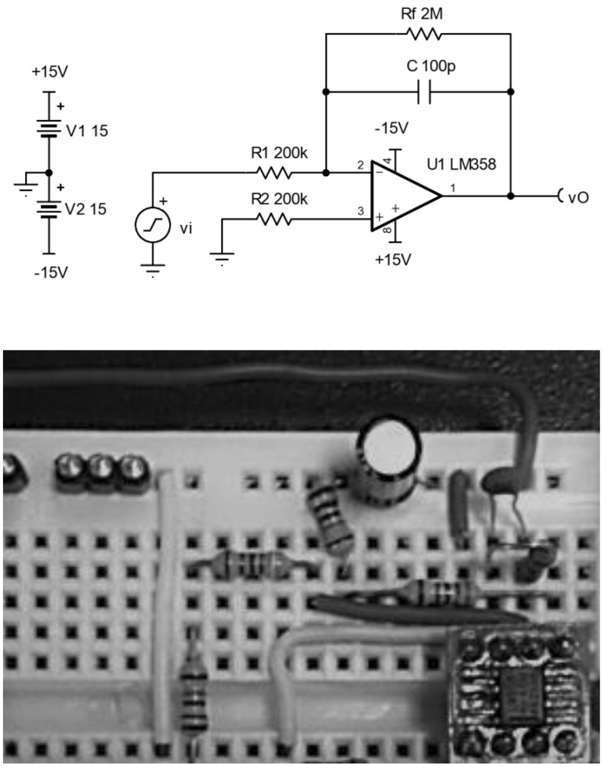

Fig. 1. Schematic and hardware circuit of integration operation circuit composed of LM358.

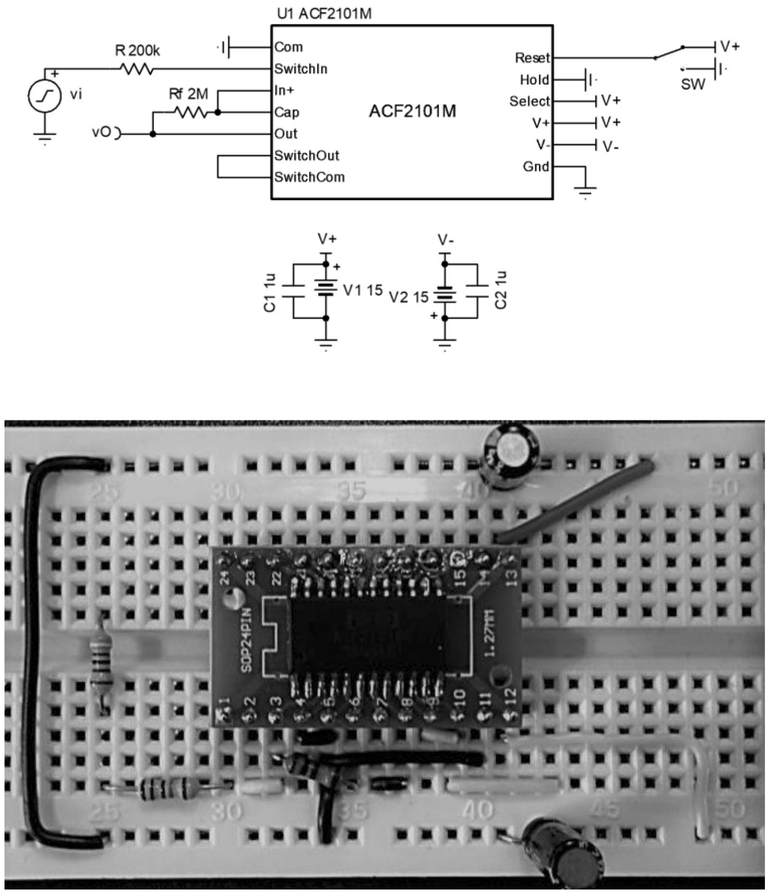

Fig. 2. Schematic and hardware circuit of ACF2101 integration operation circuit.

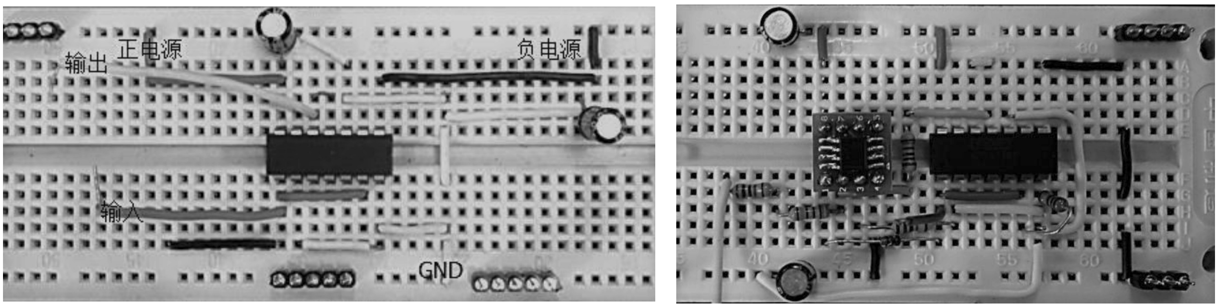

Fig. 3. Square calculation circuit and Square root calculation circuit designed with MPY634.

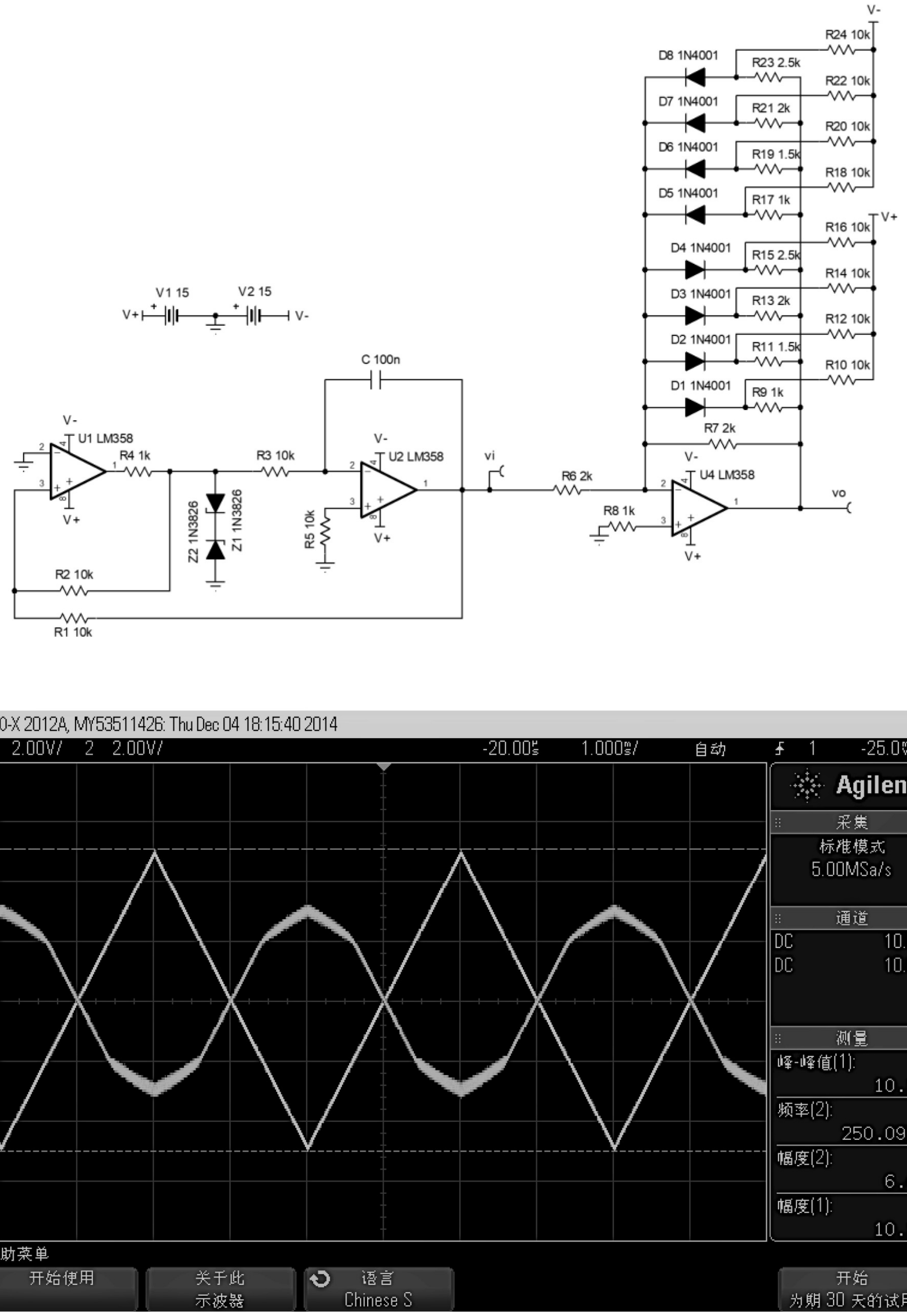

Fig. 4. Schematic and experiment result of triangular wave to sine wave conversion circuit designed with LM358.

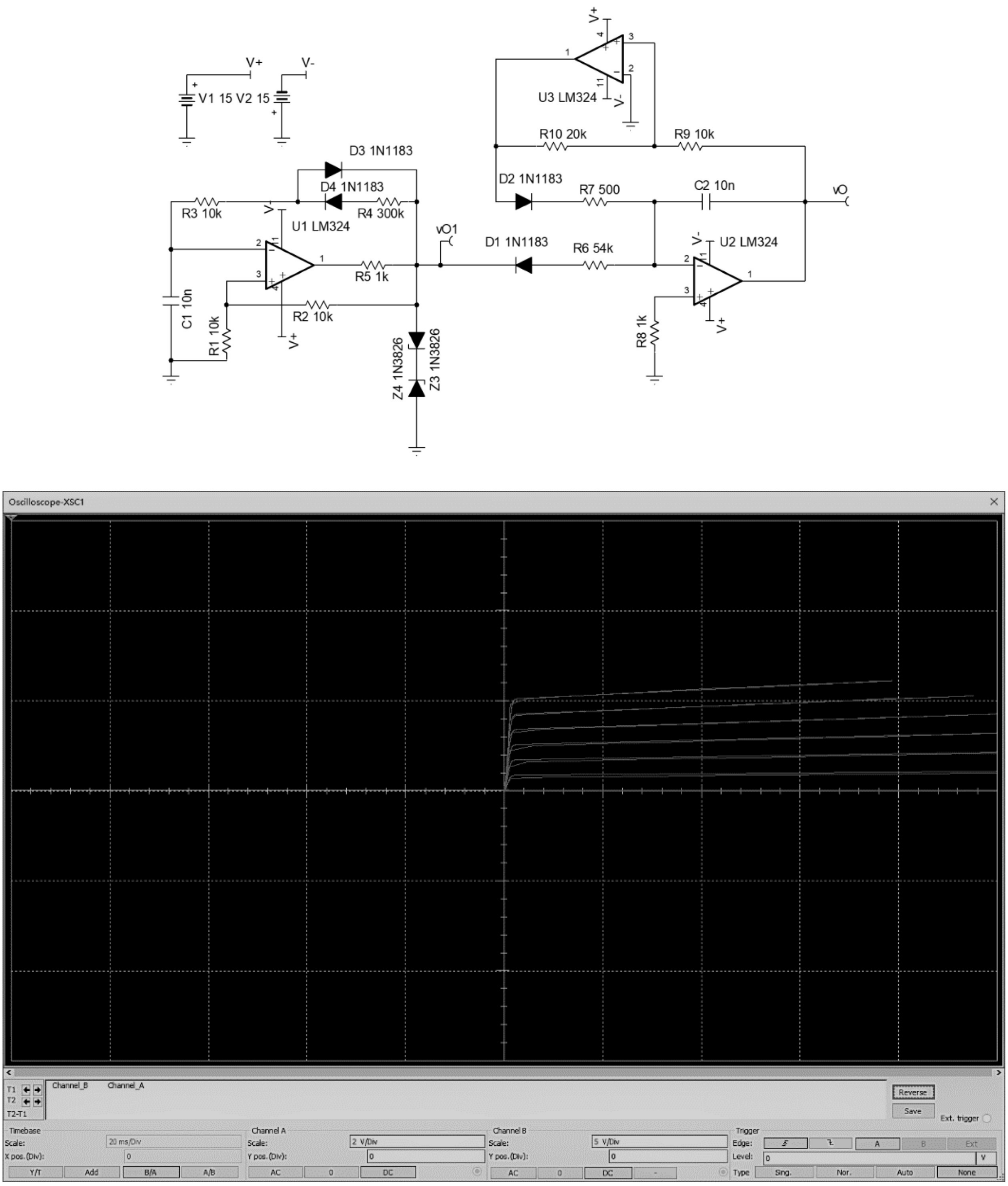

Fig. 5. Step Wave Generator and its application.

human pulse meter that counts the pulse of the human body; (5) infrared anti-theft alarm with an infrared pyro electric sensor and a buzzer or LED; (6) temperature measurement circuit with a thermistor to measure the ambient temperature; (7) PID (Proportional-Integral-Differential) temperature controlling circuit with a thermistor, a fan, and a small refrigerating sheet to measure and control the temperature of the refrigerating sheet; (8) distance measurement circuit with a ultrasonic measuring probe to measure distance; (9) light intensity measurement circuit with a photo resistor and a logarithmic amplifier log104 to measure the natural light intensity; (10) atmospheric pressure measurement circuit with a pressure sensor MPXH6115 to measure about one standard atmospheric pressure.

Some of the schematic or experimental circuits are shown in Fig. 6 to Fig. 9.

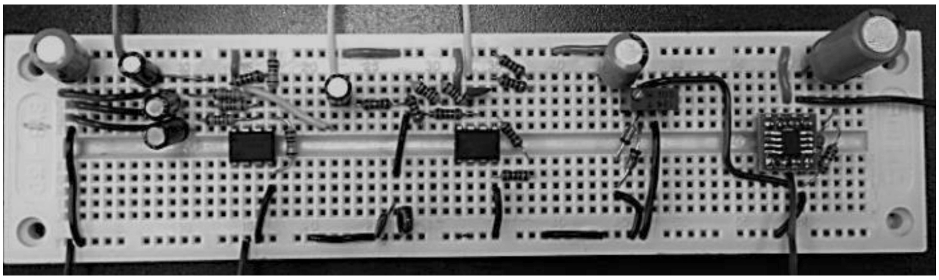

Fig. 6. Hardware circuit of audio amplifier designed with LM386.

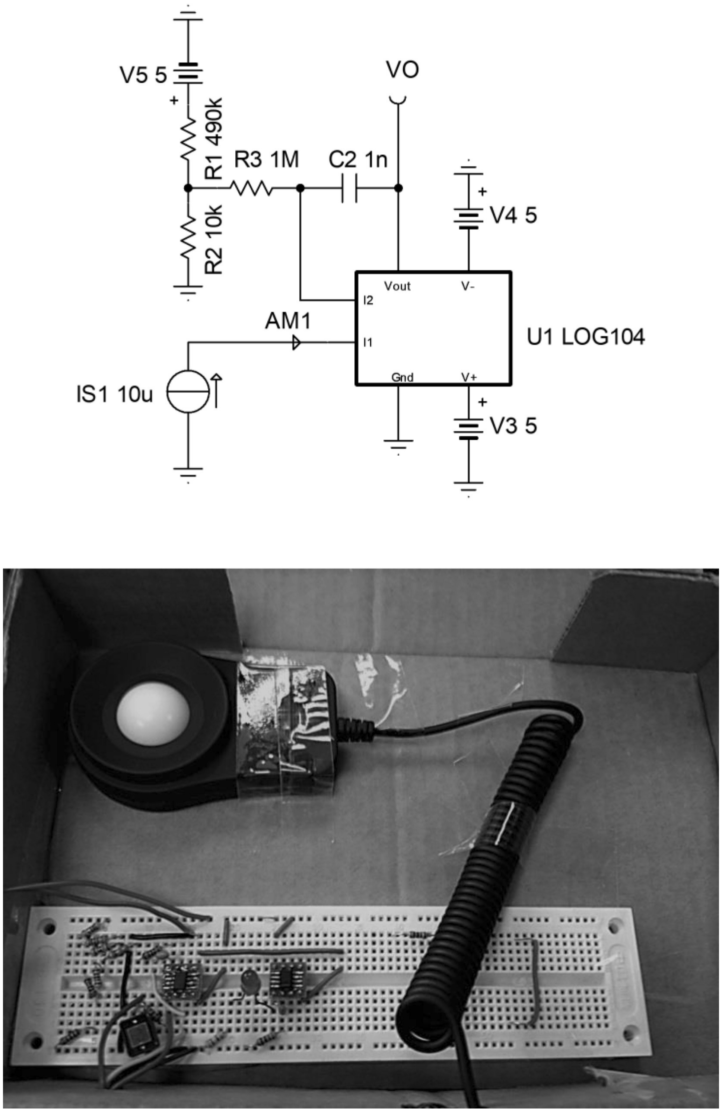

Fig. 7. Schematic and hardware of light intensity measurement circuit.

3.3 Experiment conditions and equipment

Good experimental environment and hardware equipment are necessary for students to learn and innovate independently. For example, the lab is open at fixed times or open at the time of appointment for students' convenient. In addition, various electronic components are provided, including resistors and capacitors, transistors, general purpose operational amplifiers, special function operational amplifiers, ADCs and DACs, and various sensors such as infrared pyro electric sensor, thermistor, ultrasonic sensor, pulse sensor, for students. Some of these devices are packaged as surface mount devices that cannot be directly inserted into breadboards for experimentation, thus they need to

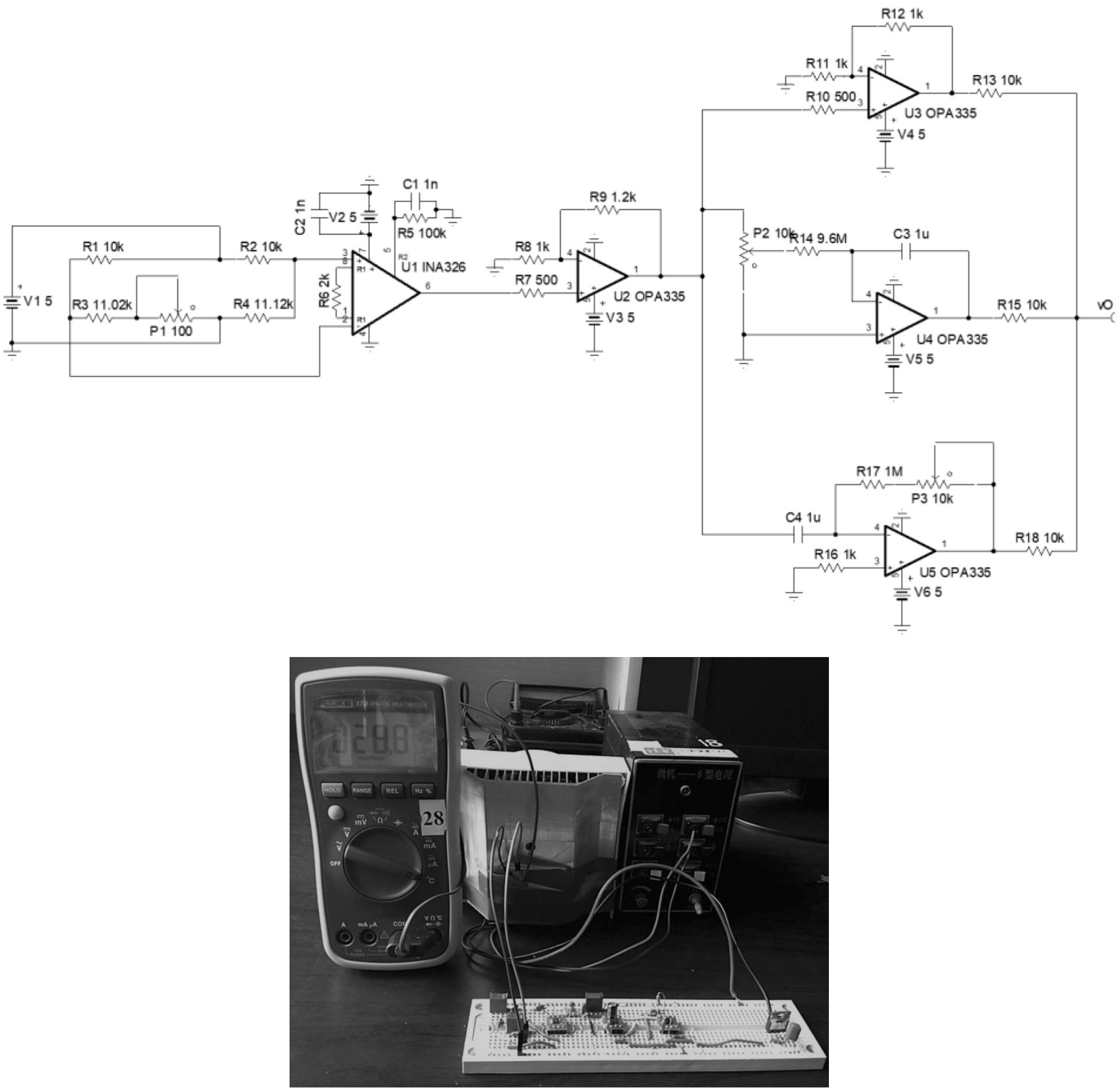

Fig. 8. Schematic and hardware of PID temperature control circuit.

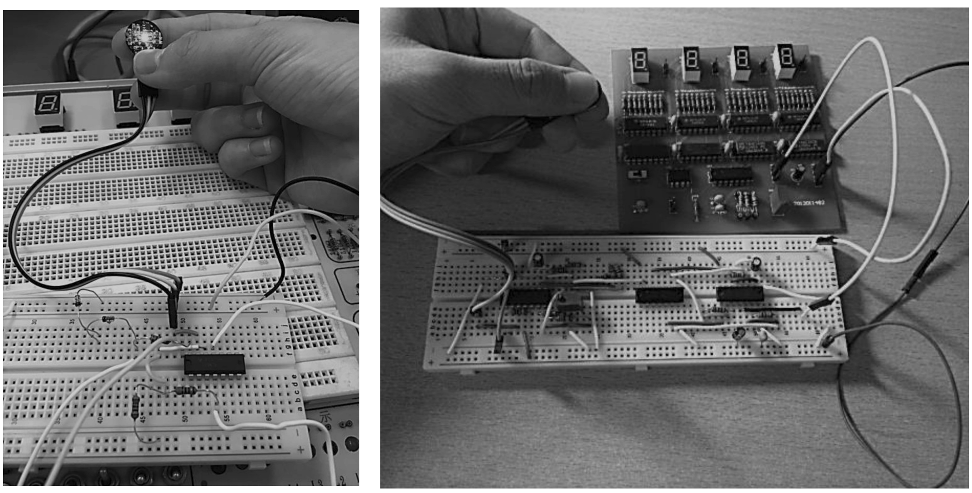

Fig. 9. Human pulse measurement circuits built by two students.

be converted to dual in-line by universal soldering plates.

In addition, each student is equipped with a lab board or breadboard, and a virtual instrument such as NI MyDAQ. Instruments not commonly used in the laboratory are also lent to students. These conditions allow students to do experiment anywhere, anytime, and also attract their research interests.

4. Results

During the teaching reform, each student can choose a design experiment according to his/her own interest, or he/she can design an innovative circuit. After finishing the experiment, every student should write a scientific paper to express his/her own experimental opinions so as to cultivate his/her writing capability.

In recent years, except for the experiments being chosen to design by students, there are also many new innovative designs made by themselves, such as follows:

1. Pythagorean Theorem Proof Circuit: a student attempted to prove the Pythagorean Theorem using a sine wave generator, an integral calculation circuit, a square calculation circuit, a summation calculation circuit, and a square root calculation circuit.

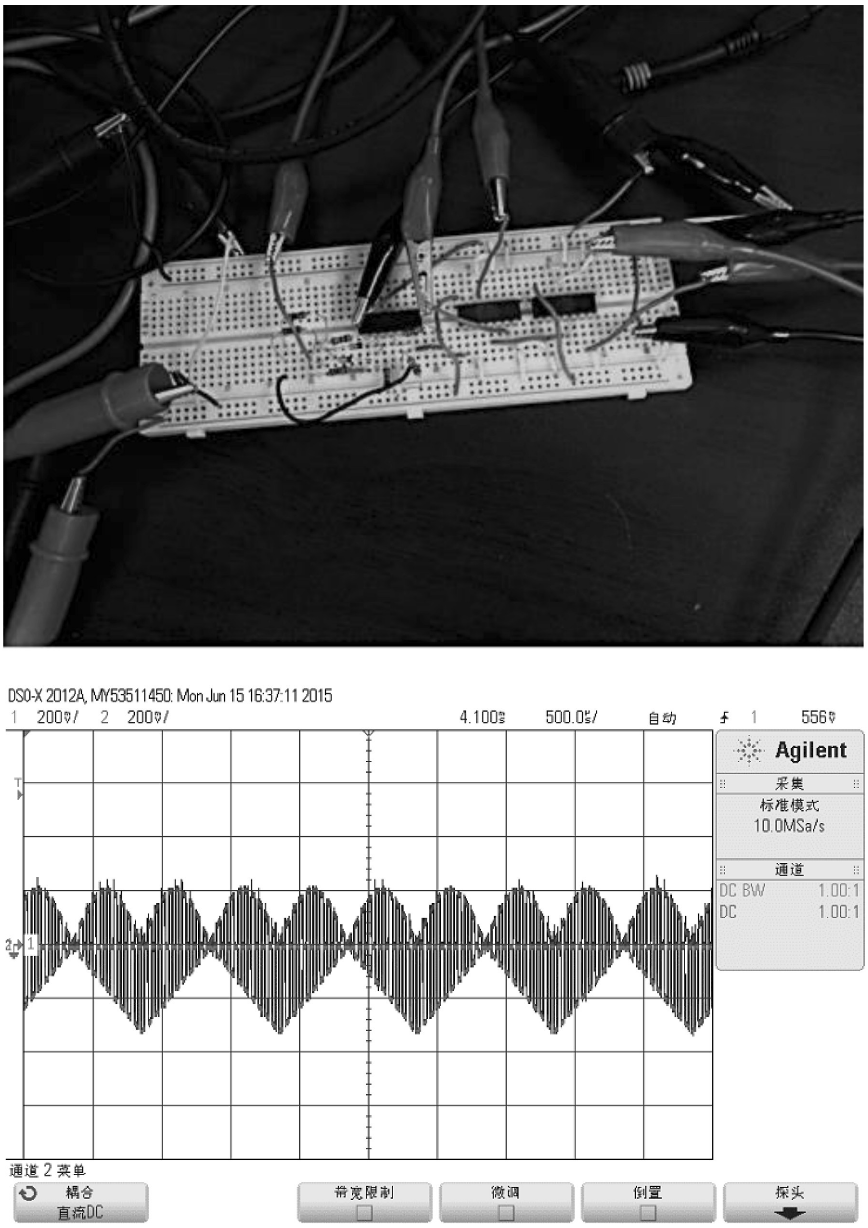

Fig. 10. Heart shape waveform circuit and the results displayed on oscilloscope.

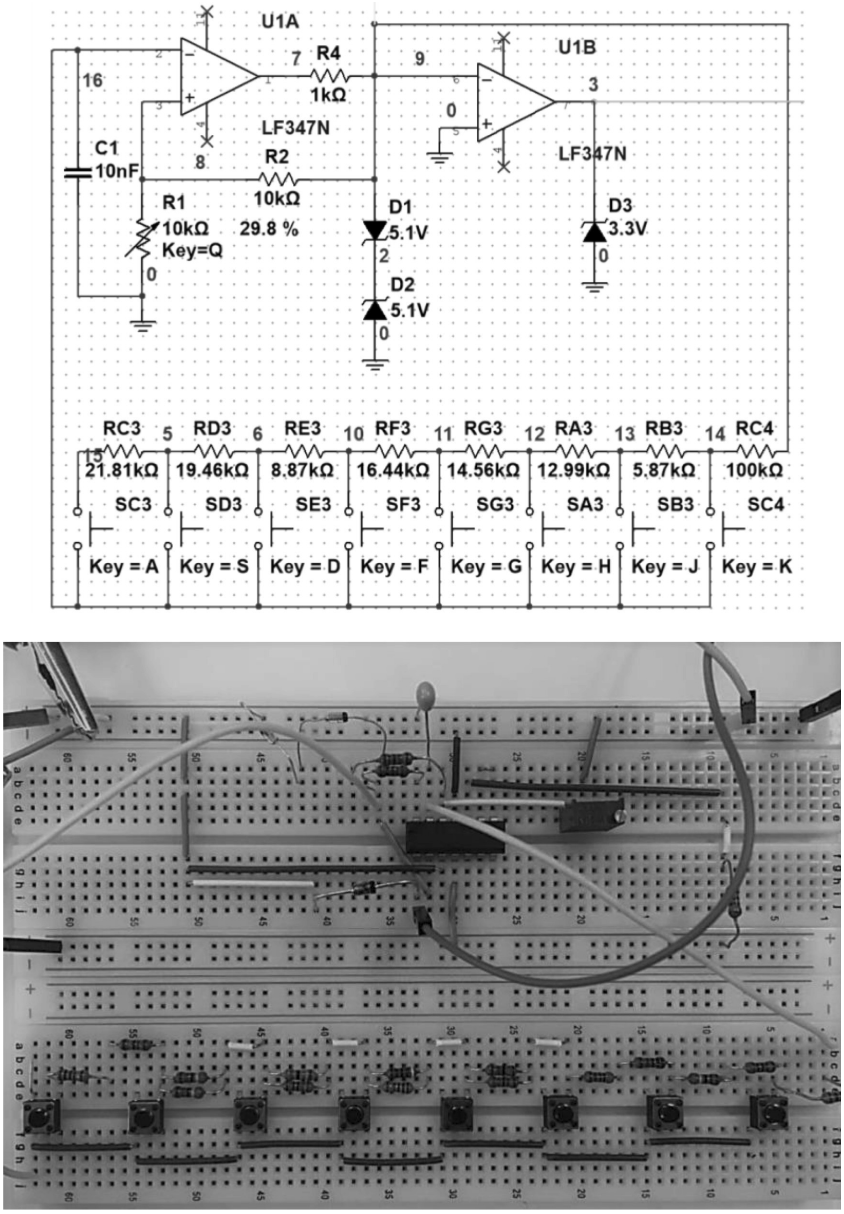

Fig. 11. Schematic and actual circuit of electronic piano.

2. Heart-shaped signal generator: a student designed a heart-shaped signal generator which uses a variety of analog circuits to form this creative electronic circuit. The circuit and result are shown in Fig. 10.
3. Capacitive touch sensing circuit: a capacitive sensor is formed by using a metal piece and a finger touching it, and used to measure the capacitance of a capacitor by a square wave generator.
4. Ultrasonic Smart Cane: a distance measurement circuit is designed with an ultrasonic probe to detect the distance between the cane and the ground to help the blind to sense the road.
5. Electronic Piano: an electronic piano circuit is designed which consists of a rectangular wave generator, a voltage comparator, and a buzzer, as shown in Fig. 11.
6. Pedometer: a pedometer with accelerometer is designed to detect the posture of the human body, and then analyze the pace signal, as shown in Fig. 12.
7. Resistance-based polygraph: when people lie, the skin resistance rises. A lie detector is designed to determine whether or not to lie by measuring the skin resistance.
8. Air Conditioning Temperature Control System: a student uses a thermistor to measure the ambient temperature and design an air conditioning temperature control system, as shown in Fig. 13.

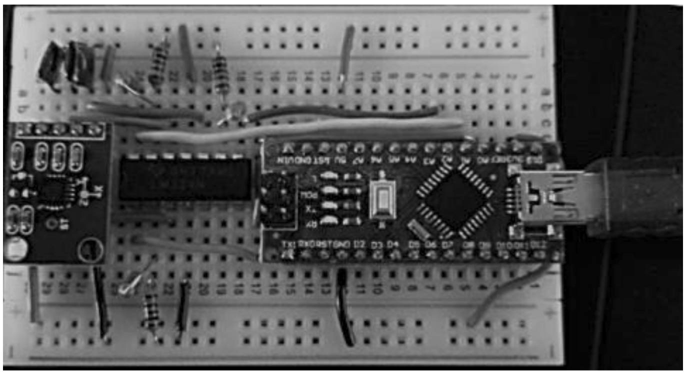

Fig. 12. Pedometer designed by three-axis acceleration sensor ADXL335.

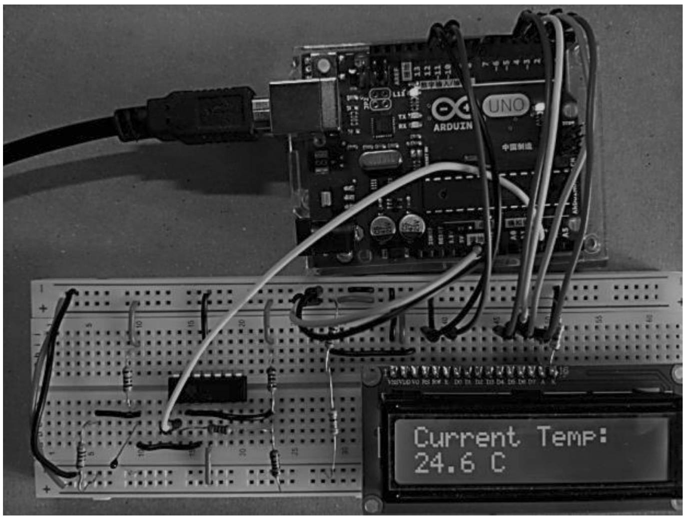

Fig. 13. Air conditioning temperature control system.

5. Discussion

5.1 Students opinions

During two years of teaching reform, the survey results for the 2016 and 2017 spring semester are shown in Table 3 and Table 4 respectively. For example, in the spring semester of 2016, the effectiveness of teaching reforms was investigated in a large class with six small classes, and 115 questionnaires were collected. The results of the experimental reform in Table 4 show that about 92% of the students agree that the experiments are conducive to cultivating their capability of creativity; about 93% of the students agree that they are good at cultivating their self-study capability; and about 97% of the students agree that they are conducive to the development of hands-on skills. In addition, another survey for the experimental equipment provided shows that 77% of the students thought that the components and the experimental boards were very helpful.

In the spring semester of 2017, the effectiveness of teaching reforms was investigated in a small class, and 25 questionnaires were collected. The results in Table 5 show that about 96% of the students agree that the experiments are conducive to cultivating their capability of creativity; about 96% of the students agree that they are good at cultivating their self-study capability; and about 92% of the students agree that they are conducive to the development of hands-on skills. In addition, for the experimental equipment provided, 63% of the students thought that the components and the experimental boards were very helpful.

The survey results show that most students are willing to use the experimental equipment for experimental research and innovation, and the experimental reform is conducive to cultivating their capabilities of research and innovation, and has achieved the expected results.

5.2 Pedagogical and creativity assessment

The pedagogical assessment of the course offered by Tsinghua University from 2016 to 2018 is shown in Fig. 14. There are seven assessment items, including course objectives, lesson plans, teacher assistance,

Table 4. Survey results of experimental reform in 2016

	Excellent	Good	General	Poor
Experiments help develop creativity	24%	40%	29%	7%
Experiments help to develop self-study capability	29%	45%	19%	7%
Experiments help develop hands-on skills	30%	39%	27%	4%

Table 5. Survey results of experimental reform in 2017

	Excellent	Good	General	Poor
Experiments help develop creativity	16%	56%	24%	4%
Experiments help to develop self-study capability	24%	56%	16%	4%
Experiments help develop hands-on skills	28%	56%	8%	8%

student recognition, student retention, teacher's teaching ability, and teacher's attitude. As can be seen from the figure, the total score of the assessment is increasing every year.

In addition, the teachers won the second prize for teaching reform results issued by the China Automation Association in 2017. In addition, some of the students in the course chose a follow-up electronic system design course. They not only showed better hands-on skills, but also made a lot of creative design, such as various robots, body pulse meters, ultrasonic range meter, etc., using sensors, analog components, MCU and FPGA.

5.3 From an international point of view

Our lab has partnered with Texas Instruments (TI) cooperation to help students design systems with analog circuits and microprocessors for several years. Last year, the lab was awarded the best joint lab award by TI because our teaching methods are very helpful in cultivating students' creativity and hands-on skills. We also wrote a book about how to teach students and engineers to design analog circuits and systems [28]. As a result, the teaching methods are not only applicable to Chinese universities, but also to other universities in the world.

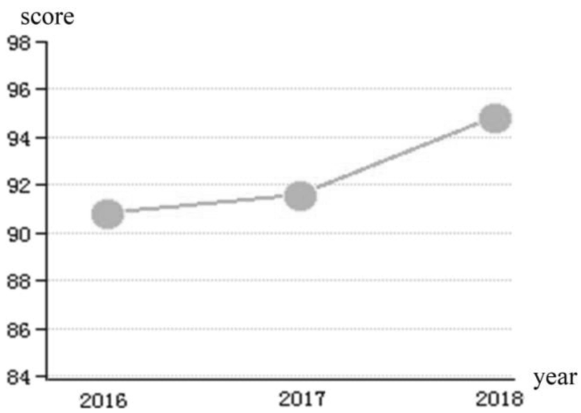

Fig. 14. Pedagogical assessment of the course.

6. Conclusion

The reform of the analog electronics technology curriculum not only adds many new circuit design and system design experiments, but also adds new content to classroom teaching. Students are free to choose circuit design and system design experiments to conduct research, and they can also try to design innovative experiments. In addition, students can experiment out of the lab using portable devices and components. After two years of teaching practice, the students' survey opinions and the university's teaching evaluation results prove that the reform method was indeed conducive to improving students' creativity, self-study ability, and hands-on skills. In addition, with cooperation with TI, our teaching methods are not only applicable to Chinese universities, but also to other universities in the world.

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