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Teaching Reform and Practice Based on Four Dimensions and One Penetration for Sensing and Detection Technology

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Abstract

Sensing and Detection Technology is a core course in engineering specialties. Traditional sensor teaching methods have obvious deficiencies in cultivating students' ability. To better foster students' comprehensive qualities, this study explored a 4D1P (Four Dimensions and One Penetration) teaching mode. We independently developed an industrial sensor teaching platform with intellectual property rights, integrating classroom and sensor experiments to address the disconnection between traditional sensor teaching and practical application. This mode combined the teaching platform with SPOC (small private online courses) and Rain Classroom teaching software, enriching classroom teaching and stimulating students' interest. By applying industry-academia-research integration to sensor teaching, students' horizons were broadened and their creative thinking enriched. The mode set up discussion-based learning in the classroom, making the class atmosphere lively. Throughout the teaching process, data-driven learning and teaching evaluation were consistently applied, allowing teachers to promptly understand students' learning situations. Data shows that under the backdrop of the COVID-19 pandemic, students' grades improved and they were satisfied with this teaching mode. This mode solves most current problems in university classroom teaching and significantly enhances students' practical abilities. It also has certain significance for education in other disciplines.

Keywords: blended teaching and learning, sensor teaching platform, integration of industry-university and research, student-centered learning, 4D1P

Introduction

The sensor is a device that can detect change in measured information and convert information into an electrical signal to meet the requirements of information transmission, processing, storage, display, recording, and control (Yuan et al., 2015). As a tool for obtaining information, sensors are increasingly recognized to be important in today's information age. Sensor technology is the pillar of modern information technology and an important guarantee for the operation of automatic measurement and control systems. With social progress, the increasing degree of automation of modern industrial production, and the pursuit of intelligent and comfortable living environments, dependence on sensors in various fields will increase. Therefore, research into sensor technology has become a key field across the world, and sensor technology has also become a key factor in the new technological revolution (O'Flaherty & Phillips, 2015). The mastery and application of sensor principles and technologies is becoming a basic skill and literacy relevant for engineers and technicians. Therefore, sensor courses are offered in many engineering programs in Chinese universities, such as Instrument Science and Technology, Mechanical and Electrical Engineering, Telecommunications Engineering, and Automation.

Sensing and detection technology is a complex discipline, involving mathematics, physics, chemistry, circuits, computer technology and other disciplines (Byukusenge et al., 2023). At present, most textbooks focus on the working principle of the sensor, and the practical application of the sensor is briefly introduced. Additionally, most sensor teaching in Chinese universities is done using teaching tools such as PowerPoint, resulting in a boring atmosphere that lowers students' enthusiasm and initiative and prevents active participation (Christensen et al., 2013). Furthermore, the disconnection between classroom teaching and sensor experiments leads to students passively receiving knowledge without having the chance to apply classroom-learned sensor knowledge to practical scenarios (Owston et al., 2013).

Nowadays, the teaching philosophy of student-centered learning (Beichner et al., 2007) is becoming increasingly popular in China. More and more Chinese universities are incorporating a wealth of online educational resources into their sensor courses to enhance teaching effectiveness. These online resources greatly mitigate the drawbacks of traditional classrooms and enrich students' knowledge (Zhao & Luo, 2020). However, these resources are mostly focused on theoretical explanations and lack introduction to sensor experiments, leading to a disconnection between theory and practice (Song & Kapur, 2017). To address this, many universities in China have set up sensor laboratories (Beichner et al., 2007), allowing students to learn to operate sensors in the lab after studying the concepts. However, due to limited lab space, there might be a considerable delay between learning the theory and practicing in the lab, which could weaken students' grasp of theoretical knowledge. Moreover, because of the large number of students, lab instructors are unable to attend to each student adequately, resulting in less precise sensor operations and suboptimal outcomes (Darling-Aduana et al., 2022).

This study analyzed the current situation of sensor teaching modes and found four main drawbacks:

1. Some students are dissatisfied with the breadth and depth of knowledge.

2. The time interval between theoretical knowledge and sensor experiments is too long.

3. Students are not highly motivated to attend class.

4. Students are unclear about the use of sensors in scientific research and factories.

These shortcomings lead to the current poor teaching effect of sensors. In order to overcome these drawbacks, we proposed a Four Dimensions and One Penetration (4D1P) teaching mode. This mode has five superiorities:

1. The mode introduces multiple online teaching resources to enrich students' knowledge.

2. The mode has a sensor teaching platform upon which students can learn sensor operation experiments remotely in the classroom.

3. In order to motivate students, the mode allows students to take part in group discussions.

4. The industry-university-research (IUR) integration enhances students' insights on the use of sensors.

5. By running teaching evaluation throughout the entire student learning process, teachers can better grasp students' learning conditions and evaluate student performance from multiple perspectives.

Preliminary results show that students were satisfied with this teaching mode; students' achievement and employment rates also improved.

Literature Review

Sensing and Detection Technology is a core course of engineering majors, which has a pivotal position in the curriculum of many majors (Gui, 2020). The teaching goal of the course is to convey the principles of sensors and develop students' ability to use sensors to solve practical problems.

Research has revealed that a variety of teaching modes are widely used in sensor education across Chinese universities. The classroom teaching mode is a traditional instructional approach. In this mode, the majority of the time is spent on teacher-led instruction, which limits active student participation (Antepohl & Herzig, 1999; Smits et al., 2003). A major drawback of this mode is the lack of sensor experiments, preventing students from engaging with real sensors and thus detaching theory from practice. With societal advancements, modern educational software is becoming increasingly common. The Lecture-Based Learning (LBL) teaching mode integrates SPOCs (Lu et al., 2012), massive open online courses (Hone & El Said, 2016), Rain Classroom (Da-Hong et al., 2020), edX (Scimeca et al., 2018), Coursera (Mukala et al. 2015), Khan Academy (Murphy et al., 2014), and other modern teaching platforms (Balog & Pribeanu, 2010; Oproiu, 2015). Although these platforms can enrich students' knowledge, their content mostly explains the principles of sensors and lacks teaching of sensor experiments (Zeng et al., 2020). To make students more active in the classroom, some scholars have proposed a team-based learning (TBL) teaching mode, dividing students into groups to discuss problems and learn from each other in the classroom. This teaching mode can mobilize students' enthusiasm for class (Okebukola & Jegede, 1988) and help students better understand classroom content (Silberman et al., 2021; Michaelsen et al. 2023). However, when the teacher's grouping of students is fixed, it may separate good students from bad students, making it difficult for poor students to get help and not significantly improving overall class performance. After analyzing many teaching cases in Chinese universities, some Chinese scholars have proposed the BOPPPS teaching mode, which consists of six stages: bridge, objectives, pre-assessment, participatory learning, post-assessment, and summary (Brown et al., 2021). The BOPPPS teaching mode focuses on interaction and reflection, and can stimulate students' enthusiasm in the classroom, improve teaching efficiency, and make students the centre of the learning process (Liu et al., 2022). However, this mode does not reasonably arrange sensor experiments, separating theoretical knowledge from sensor experiments (Ma et al., 2021). Project-based learning (PBL) is a teaching mode that combines theoretical knowledge with practice. After mastering theoretical knowledge in the classroom, students conduct relevant sensor experiments in the laboratory (Shi et al., 2018; Shin et al., 2021). Affected by teaching conditions, many universities in China lack resources, and schools need to reasonably arrange students' class schedules to allow students to conduct sensor experiments. Still, there may be a long gap between theoretical knowledge learning and experimental operations. When students start experiments, they may have forgotten the theoretical knowledge they learned (Sari & Prasetyo, 2021).

Currently, Chinese universities teach students to conduct sensor experiments mainly through virtual teaching platforms or Internet of things (IoT) experimental platforms. The virtual teaching experiment can meet student requirements through the virtual instrument software that allows students to design their own sensor experiments to measure physical quantities, but this method gives students contact with only a virtual sensor. Hence, students remain unfamiliar with sensors when they encounter them in real life (Dong et al., 2022; Song et al., 2020). Most universities have set up special sensor laboratories where students can use IoT platforms to conduct sensor experiments (Lui et al., 2023; Tran et al., 2021). Although these experimental platforms can meet the needs of students for sensor experiments, most universities have more students and less experimental equipment, which leads to the issue of meeting the needs of all students in a timely manner (Honar Pajooh et al., 2022).

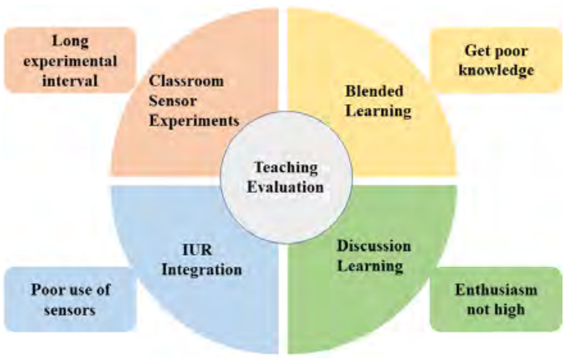
Since these teaching modes and platforms have shortcomings and are not well-suited for modern sensor education, we integrated the strengths of the LBL, TBL, BOPPPS, and PBL teaching modes and, in conjunction with a proprietary industrial sensor teaching platform, developed the 4D1P teaching mode. This mode was implemented in the sensor courses at Hunan University in 2021 and has received very positive feedback from students.

Theory and Methodology

This innovative teaching mode, 4D1P, is shown in Figure 1. Four Dimensions includes blended learning, classroom sensor experiments, IUR integration, and discussion learning. One Penetration means that teaching evaluation is integrated throughout the entire instructional process. The coloured boxes outside the circle show the four main drawbacks to current teaching modes which were listed in the Introduction section of this article.

Figure 1

4D1P Teaching Mode Framework



Note. 4D1P = four dimensions & one penetration.

Before showing the results of this research, the four dimensions and teaching evaluation are discussed in the sections that follow, beginning with blended learning.

Blended Learning

With the popularization of computers and the Internet, traditional textbook teaching can no longer meet current requirements. More universities are adding online educational resources to classroom learning, forming a blended learning mode (Boelens et al., 2017). This learning mode can combine the advantages of traditional learning with the advantages of online learning, each complementing the other to achieve the best learning effect (Newby et al., 2000).

Currently, there are various types of online learning tools around the world. After comparing multiple online learning tools, we developed and implemented a blended learning method based on SPOC and Rain Classroom (Chen et al., 2022). With this mode, before class, the teacher publishes the content that students need to preview on the SPOC software. For difficult and abstract parts of the lesson, the teacher uploads videos to the SPOC software, so students can understand these contents more easily. At the same time, in order to consolidate students' knowledge, SPOC software assigns some online questions. In class, Rain Classroom software displays courseware to the students. The teacher then assigns similar questions in the Rain Classroom based on students' answers to the SPOC questions to further consolidate knowledge points. Students mark unfamiliar knowledge points on the Rain Classroom software. After class, students can also log on to Rain Classroom to review courseware and difficult content. The content that students have not yet understood or have forgotten in class can be reviewed this way as well. In addition, more than 30 courseware and short videos were made and uploaded in the SPOC software. The teacher analyzes the results of SPOC and Rain Classroom tests every semester, finds out students' missing knowledge points, and focuses on these knowledge points in the next semester. The teacher will also find out students' most difficult to understand knowledge points based on browsing records, then supplement the corresponding knowledge points on the software and focus on introducing them in the next semester's teaching. After several years of experiments and adjustments, the blended teaching mode of offline SPOC and online Rain Classroom has been fully formed, strengthening students' knowledge foundation, expanding their horizons, and allowing students to acquire more useful knowledge.

Classroom Sensor Experiments

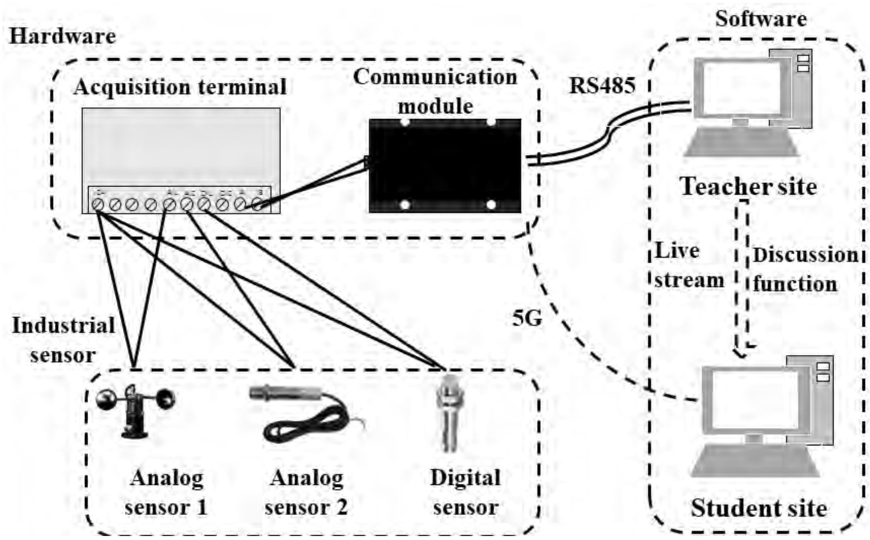
Sensor Teaching Platform

Sensing and detection technology is strongly an applied subject, where students need to learn theoretical knowledge as well as how to use sensors. In large teaching classrooms, students cannot see sensor experiments conducted at the front of the room very well. For example, students sitting at the back will not be able to see much detail. In the laboratory, students cannot understand how sensors are used in real industrial environments, as sensor experiments in a lab are disconnected from reality. To allow students to better watch sensor experiments in real industrial environments, we developed an industrial sensor teaching platform with intellectual property rights. A schematic diagram of the sensor teaching platform is shown in Figure 2; it consists mainly of industrial sensors, hardware, and software. Sensor data is collected through the collection terminal. The collected data can be transmitted to the teacher's computer via the RS485 communication protocol or to the student's computer via 5G. At the same time, the teacher's computer can also transmit operation videos, chat content, and experimental data to the student's computer via remote live broadcast and discussion functions.

This platform is suitable for industrial sensors with a 4-20mA output. Industrial sensors whose output is not 4-20mA can also be used on this teaching platform after conversion to 4-20mA through a converter. We purchased 10 types of analog sensors, covering most of the sensor knowledge points in sensing and detection technology, for use in this course.

Figure 2

Schematic Diagram of the Sensor Teaching Platform



Note. RS485 is a communication protocol used in this platform.

The hardware part of this platform consists of a collection terminal and a communication module. The collection terminal is a multi-channel IoT collection terminal that can simultaneously collect data from multiple sensors. The communication module consists of an RS485 communication protocol and a 5G module. RS485 can transmit data collected by the terminal to the teacher’s computer via a USB interface. The 5G module ensures that the teacher’s operation screen and collected data can be displayed in real-time on a student’s computer.

The software part of this platform is written in Python and PyQt. To more accurately display data on the software interface, it is necessary to calibrate the data collected by the collection terminal. Users need to set an accurate linear calibration formula according to the specifications of the sensor, and the calibration formula will be saved in the platform’s database for direct use in the next experiment. In addition, an interface for displaying measurement data is designed, and the background will automatically produce a line chart of all data collected in the experiment for teachers and students to analyze. Through the video live broadcast function of this platform, students can immediately watch sensor operation experiments in real industrial environments, which will help students use sensors in future in real life. To better communicate and interact with students in the classroom during remote experiments, this platform has a discussion room. Students and teachers can promptly communicate any questions about operation experiments in the classroom.

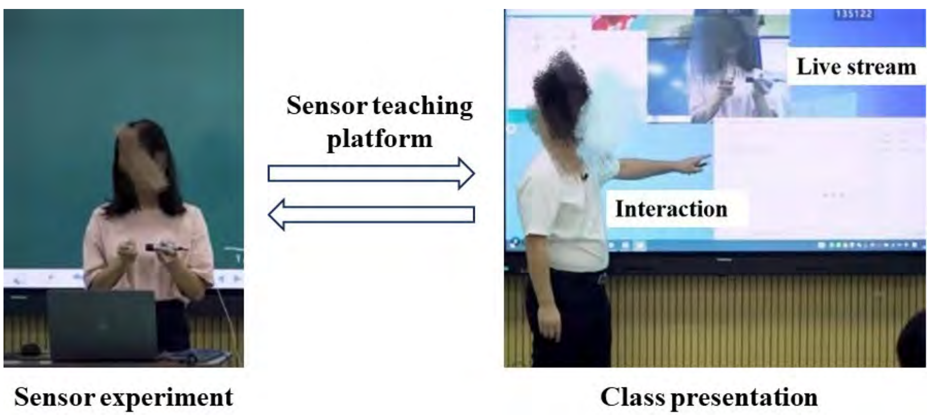
We partnered with companies to mass produce this sensor demonstration platform, which universities can purchase at an affordable price. This demo platform is user-friendly and easy to operate. Users simply need to connect the sensor to the demonstration platform according to the operating instructions and then adjust the linear calibration to display sensor data in real-time on a computer. The platform also includes a database feature, which facilitates the retrieval of past operational data by teachers.

Measurement Experiment

For this study, we applied the sensor demonstration platform to sensor courses offered at Hunan University. As the platform can collect experimental data from multiple sensors simultaneously, it aids in setting up comparative experiments to demonstrate the use of different sensors. Through this comparative approach, students can better understand the principles and characteristics of each sensor. Figure 3 shows an example of a comparison experiment being demonstrated and livestreamed and the role played by the sensor teaching platform in facilitating interaction between the laboratory teacher, the classroom teacher, and students.

Figure 3

Sensor Experiment Demonstration Showing the 4D1P Teaching Platform



The experiment shown in Figure 3 is a comparison experiment that used two different sensors to measure distance. Distance is a physical quantity that measures the length from one object to another. In daily life, various sensors can measure distance. In this demonstration experiment, an eddy current sensor and a laser distance sensor were used. The principle of distance measurement by the eddy current sensor is based on the eddy current effect produced by the movement of a metal plate. When a metal sheet moves near the sensor, the sensor will generate an induced current, and the current size can be converted into distance through a conversion formula. This sensor is a non-contact sensor with strong resistance to external interference, suitable for measurement in harsh environments, but it can only be used for current measurement on conductive materials. The theory of distance measurement by the laser distance sensor is to emit infrared rays from the sensor, which are reflected back to the sensor when encountering an object, and the time difference is converted into distance. This sensor is also a non-contact sensor, with a fast response time, capable of completing distance measurements in a very short time, suitable for applications requiring high real-time performance, but it is not suitable for use under strong light irradiation.

In the experiment shown in Figure 3, the teacher in the industrial environment used the eddy current sensor and laser distance sensor to measure the distance between objects. Through the communication module of the sensor teaching platform, the operation video and sensor measurement data were transmitted to the classroom as the classroom teacher and the laboratory teacher jointly explained the experiment. Students could ask questions to the two teachers through the discussion room function. Some of these questions were directly answered by the experimental teacher's operation of the sensor, as students will better understand these problems when they see them rather than through mere theoretical explanation.

Through this platform, it was possible for the teacher to demonstrate the use of multiple different sensors in the classroom at the same time. Through different sensor measurement experiments on the same physical quantity, students could better understand the practical application of sensors in real life and have a deeper understanding of the principles and characteristics of sensors.

IUR Integration

With the development of society, traditional school education can no longer meet social needs. In order to cultivate high-quality talent that meets market demands, some scholars have proposed a teaching mode that has a close cooperative relationship between schools and enterprises, integrating the actual needs of enterprises and students' knowledge and skills in the teaching process (Kinshuk et al., 2013). This mode could provide students with professional knowledge, promote effective communication between enterprise and schools, achieve improvement of teaching modes, and enhance discipline development and innovation. This mode could make full use of various teaching environments and resources among industries, universities, and research institutions, as well as their respective advantages in talent cultivation (Xie 2019). What's more, the mode could also organically combine school education focusing on imparting knowledge in the classroom with education forms that directly acquire practical experience and scientific research practices. This is a fundamental scheme to solve the problem of the disconnection between school education and social needs, narrowing the gap between school and society in talent cultivation, and enhancing the competitiveness of university students.

To help students better understand the application of sensors in laboratories and production industries, we organize students to visit the school's research laboratories and some sensor factories once a month, allowing students to master the use of sensors through actual cases of scientific research and industry and gain some innovative inspiration (Zheng et al. 2021). In addition, students are assigned sensor design homework, requiring them to choose sensors learned from a textbook for specific scenarios to solve practical problems in industry and scientific research. An example from this assignment would be how to use sensors to design a rainwater detection device. Students would first need to provide a solution, then build their sensor detection system based on this solution, and finally present the final detection effect in the classroom, while the teacher poses questions. This design homework is evaluated based on the detection effect of the student's solution and their response to questions. By completing this homework, students can solve actual problems through hands-on practice, while enhancing their understanding of classroom knowledge points.

Discussion Learning

At present, university students' enthusiasm for attending classes is generally not high, leading to low classroom efficiency (Larson & Keiper 2002). Although some teachers also introduce discussions into classroom teaching, they do not have many restrictions on student grouping, which can lead to students with good academic performance gathering in the same group, resulting in poor overall effectiveness of student group discussions, where some students are left behind.

In order to prevent high-achieving students from clustering, we dynamically group students based on the results of SPOC software tests. During class, teachers pose questions about sensor applications or experiments and ask students to discuss these within a designated time frame. Each group is then required to choose a representative to present their discussion results. If students have doubts about these results, they are encouraged to raise objections, fostering their ability to question. This method significantly enlivens the classroom atmosphere, stimulates students' interest in learning, and deepens their understanding of sensors. The 4D1P teachers also record the discussion and award points to the speaking representatives and those who raise questions, with the possibility of accumulating up to 10 points.

Teaching Evaluation

Previously, traditional course evaluations relied mainly on final exams and homework, ignoring sensor experiments and classroom tests, bringing great limitations. To strengthen the evaluation of student learning outcomes, we developed a comprehensive multi-assessment system for this course, including midterm and final exams, sensor design homework, experiments, discussions, Rain Classroom tests, and SPOC tests. Before each class, the lecturer prompts students to preview and complete online questions using the SPOC software. Since this part primarily involves understanding students' pre-class preparation, the standardized scoring for this section is set at 10 points. In the classroom, open-ended questions promote group discussions, awarding points to speaking representatives and students who raise doubts, with this scoring standard accumulating also a total of 10 points. In addition, the teacher arranges classroom tests through Rain Classroom, and the scores obtained by students at the end of the course are converted into a standardized score of 10 points. In addition, half an hour before class, students present their sensor detection systems, and the lecturer scores them, based on the detection effect and Q&A situation, for another total score of 10 points. The midterm exam, arranged after six weeks of the course, evaluates students' learning situation, with a total score of 20 points. The final exam, arranged two weeks after the end of the course, evaluates students' learning situation in the semester, with a total score of 30 points. The cumulative score of these different evaluations is 100 points. By adopting this evaluation system, dividing the total score into the sum of scores of many small tasks, instructors ensure that students can concentrate on completing each small task, allowing students to participate in every part of sensor teaching. This diversified evaluation method aims to compensate for the problem of insufficient attention in the classroom and more comprehensively understand students' performance throughout the course. This evaluation system is applicable to courses other than sensor courses.

Table 1

Multiple Evaluation System for the Sensor and Detection Technology Course

Evaluation mode	Mid-term	Final	Sensor design task	Process evaluation				Total
				E	D	RC	SPOC	
Points *n*	20	30	10	10	10	10	10	100

Note. E = experiment; D = discussion; RC = Rain Classroom test; SPOC = SPOC test.

Results

Previous teaching methods for the Sensor and Detection Technology program have been diverse. However, since 2021, the 4D1P teaching mode has been widely used in Hunan University. In comparison to previous teaching methods, the 4D1P mode has resulted in significant improvement in students' academic performance, and students have gained a deeper understanding of sensors. Additionally, according to an anonymous survey distributed to students at the end of the semester, students are satisfied with the teaching mode and believe that their abilities have been enhanced.

Rain Classroom Test Data

Rain Classroom is a teaching software for real-time classes. It can help students take class tests and consolidate knowledge learned in class. Since 2017, Rain Classroom has been used in the Sensor and Detection Technology course. As shown in Table 2, with the continuous improvement of Rain Classroom functions, the number of questions (NoQ) increased year by year. There were only 15 questions in 2018, but the NoQ in 2022 was 43; in just four years, the number of problems increased nearly threefold. The reason for this phenomenon is that the teacher supplements the questions based on students' learning situations.

Table 2

Rain Classroom Testing Results

Measure	2018	2019	2020	2021	2022
NoQ	15	34	30	39	43
AAR (%)	53.31	57.78	49.43	56.89	60.30

Note. NoQ = number of questions; AAR = average accuracy rate.

In addition to the increase in the NoQ, the average accuracy rate (AAR) of students has also improved, with the exception of 2021. For example, the AAR in 2018 was 53% and the ARR in 2022 was 60%. The AAR was relatively low in 2020 because of the impact of the COVID-19 pandemic, when the school had to adopt online teaching, which greatly reduced the teaching effect. Besides the overall improvement in teaching, there was increased accuracy for questions in three chapters which have sensor experiments. This improvement is shown in Table 3. Before 2021, the accuracy growth in Chapter 2 was relatively slow. After 2021, the 4D1P teaching mode was used. Despite the COVID-19 pandemic, students gained a deeper understanding of sensor experiments. This data suggests that the 4D1P mode helps students improve their mastery of the course knowledge.

Table 3

Percent Accuracy of Student Responses to Questions Related to Demonstration Experiments

Chapter	2019	2020	2021	2022
2-1	6.3	12	11.3	29
2-2	17.5	14	12.1	41.0
2-3	40.7	70.5	52.5	73.0

SPOC Test Data

After professors at the University of California, Berkeley proposed the concept of SPOC, teaching institutions around the world began incorporating the SPOC concept into the classroom. Currently, many SPOC online education platforms and corresponding software have emerged in China. In order to better broaden students' knowledge, SPOC software was introduced in this sensor course in 2020 for students' preclass preview. Before class, the teacher arranges for students to preview contents on the SPOC software, and at the same time, SPOC software offers some classroom tests to measure students' learning effectiveness. Table 4 shows the average scores for each weekly test in the 2020–2022 SPOC courses. As shown, the score of students is increasing year by year, from 93.09% in 2020 to 94.32% in 2022, which suggests that students have more profound understanding of theoretical knowledge and have greatly improved their learning efficiency.

Table 4

2020–2022 Average scores for tests in the SPOC course

Week	2020	2021	2022
1	7.1/8	11.1/12	10.9/12
2		11/12	11/12
3	10.9/12	11.2/12	11.3/12
4	13.8/16	14.5/16	15.4/16
5	13.5/14	13.3/14	13.5/14
6	9.6/10	9.8/10	9.6/10
7	7.3/8		7.8/8

8	11.7/12	11.6/12	11.5/12
9	9.6/10		9.6/10
10	9.6/10	8.9/10	8.9/10
11	9.3/10	9.4/10	9.2/10
Average score (%)	93.09	93.33	94.32

Note. Empty cells indicate there is no class in this week.

Final Multiple Evaluation

Before 2021, the BOPPPS teaching mode was the main mode used in the Sensing and Detection Technology course at Hunan University. Since 2021, the teaching mode has changed to 4D1P. In order to better evaluate students' learning situation, we proposed a diversified course evaluation system. As was shown in Table 1, the overall course grades were composed of seven parts: midterm exam, final exam, sensor design assignment, sensor experiment, classroom discussion, Rain Classroom test, and SPOC test. These evaluation metrics correspond to the 4D1P teaching mode. This evaluation system has the potential to improve students' overall quality, students can improve practical skills through the experimental part, team cooperation ability through the discussion part, mastery of knowledge points through exams, and their ability to solve life and scientific research problems through sensor design homework. Table 5 displays the results of the final multiple assessments for the years 2018–2022, during which the course scoring system and course content did not change. From Table 5, it can be seen that compared to the BOPPPS teaching mode, the 4D1P teaching mode significantly improves students' grades and since the standard deviation has decreased, this result may indicate that this improvement is more consistent.

Table 5

Results of Students' Final Marks Under the Multiple Evaluation System

Year	Students *n*	Average score	*SD*
2019	67	80.4	6.8
2020	67	81.3	7.8
2021	68	82.1	7.0
2022	61	82.9	6.0

Classroom Survey

In order to understand students' views on the 4D1P teaching mode, an anonymous questionnaire was sent at the end of the 2021 semester to 62 students participating in the study through the WeChat group, and 48 responses were received. Several typical survey questions and their corresponding results are listed in Table 6. It can be concluded from these results that: (a) students recognize that this teaching mode can stimulate their interest in learning ; (b) they believe that this teaching mode can help them better master laboratory skills; (c) most students believe that this teaching mode can enable them to better master theoretical knowledge; (d) they think that they can better participate in classroom teaching; (e) most students are satisfied with this teaching mode ; and (f) they are also willing to share this teaching mode with other students. Students are quite satisfied with this teaching mode. In addition, they think the teaching mode is better for them to understand knowledge and master sensor experiments.

Table 6

Results of the Student Survey About the 4D1P Teaching Mode

Question	*M*	*SD*	Minimum
Do you think the teaching mode inspires your interest?	9.20	0.60	8
Do you think the teaching mode is helpful for your mastering of experiment skills?	9.42	0.51	9
Do you think the teaching mode is better for you to understand knowledge?	9.51	0.48	9
Do you think the teaching mode will enable you to better participate in the classroom?	9.38	0.67	9
Are you satisfied with the teaching mode?	9.19	0.85	8
Will you recommend the teaching mode to other students?	9.13	0.77	8

Note. $n = 48$. Survey scale ranged from 1 (*weakly*) to 10 (*strongly*).

Conclusion

In alignment with the student-centered teaching concept, this research examined the 4D1P teaching mode applied to the Sensor and Detection Technology course of Hunan University. This teaching mode also solved the four drawbacks of the current sensor course:

1. Students' breadth of knowledge was enriched through the hybrid teaching method of SPOC+ Rain Classroom, the introduction of multiple courseware and videos from online courses, and the design of multiple courseware and micro-videos according to university requirements.

2. The sensor teaching platform brings industrial sensor experiments into the classroom, so that students can learn sensor operation by remote video live broadcast after learning theoretical knowledge. As a result, students become equipped to more conveniently use sensors to solve

practical problems in their future lives.

3. Students' creativity was stimulated as a result of visiting the school's sensor research laboratory and sensor factory and seeing the practical application of sensors in scientific research and production.

4. Students were more able to participate in discussions in class since the teaching mode dynamically groups students according to their pre-study grades and sets up open-ended questions about sensor experiments in class, so that students' enthusiasm in class improved.

In addition, a diversified curriculum evaluation system that can better evaluate students' comprehensive qualities was introduced. This evaluation system runs through the entire process of learning about sensors. According to the results of the questionnaire and the grades of students, it can be seen that students are very interested in this teaching mode, and this teaching mode has a significant impact on improving grades. The 4D1P teaching mode can not only be applied to sensor courses, but also to courses such as optoelectronic detection, image processing, non-destructive testing, Structural Health Monitoring, fault diagnosis, and so forth. However, the 4D1P teaching mode still has the following drawbacks:

1. This teaching mode requires active participation from students and will consume a considerable amount of their spare time.

2. This teaching mode requires the support of the school's strong scientific research capabilities in order to provide students with a broad sensor experimental platform.

3. This teaching mode also requires a considerable amount of effort from the teacher, usually requiring the assistance of a teaching assistant.

Future sensor teaching should integrate more high-tech technologies to provide richer, personalized learning experiences. Schools will need to establish closer cooperation with enterprise to provide more practical opportunities to cultivate students' ability to solve practical problems.

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Declarations

The authors declare that they have no competing interests.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Informed Consent

All participants were informed about the aim and scope of the study as well as the ways the data would be used. The respondents' participation was completely consensual, anonymous, and voluntary. Informed consent was obtained from all individual participants included in the study before they participated in the survey. The rights of respondents are safeguarded in this study in line with the Declaration of Helsinki.

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