A Hierarchical Probe Evaluation Method for Teaching Effect of University Engineering Courses Based on the Keypoints of Knowledge

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Abstract. It has been five years since China's higher education entered the stage of universal education. With the increase of the gross enrollment rate of college students, the differences of students who choose courses jointly have increased significantly. The traditional average evaluation method of all-aspect framework tends to weaken the evaluation, supervision and help of course teaching. In this paper, a probe deep detection method is proposed. The key knowledge points of the course are selected, and the position of each student's learning effect is evaluated by nine levels. The selection principle of key knowledge points and the implementation method of probe evaluation are put forward. Taking the Mechanics of Materials and Pumps and Compressors of two university engineering courses as examples, the construction idea of hierarchy criterion is demonstrated.

Keywords: University courses; Teaching evaluation; Keypoints of knowledge; Probe; Hierarchy.

1 Introduction

The gross enrolment in higher education in China has been growing steadily. In 2002, it reached 15.0%, and in 2019, it exceeded 50 percent for the first time, at 51.6 percent. The gross enrolment rates for the year of 2020, 2021 and 2022 were 54.4%, 57.8% [1] and 59.6% [2] respectively. China's higher education from the elite education, through the mass education, had entered the stage of universal education. It took only 17 years to move from the mass education to the universal education, and the stage of education was crossed very quickly.

After entering the stage of universal higher education, local institutions of higher learning were the most impacted due to the overall decline in the quality of college enrolment sources. The following characteristics of students are relatively common:

(1) Weak ability of self-management.

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(2) Left the supervision of parents and teachers in middle school, it is easy to appear the lazy of "free oxygen drunk".

(3) Accustomed to one-dimensional learning in secondary school, not to the pace of learning and the way of assessment in the university.

(4) Little understanding of the university majors.

However, many teachers still follow the teaching method of the elite education in the classroom, and there will inevitably be a serious separation between teaching and learning.

The Chinese education sector's demand for the quality of university teaching has not been reduced, a series of measures, such as Undergraduate Education Teaching Review and Evaluation, China Engineering Education Certification, Construction of National Program of Web-Delivery for Elaborate Courses, Construction of National First-class Courses, etc., are aimed at ensuring the basic quality of university education and actively guiding the healthy development of China's higher education. The Undergraduate Education Teaching Review and Evaluation focuses on keeping the bottom line of university education. China Engineering Education Certification focuses on ensuring that graduates meet the basic requirements of society and industry. The main function of National Program of Web-Delivery for Elaborate Courses and National First-class Courses is demonstration and guidance.

The Undergraduate Education Teaching Review and Evaluation (2021-2025) [3] adopts four evaluation schemes in two categories, one evaluation scheme in the first category and three evaluation schemes in the second category. The first category is suitable for domestic first-class universities and aims at international first-class universities. The second category is other colleges and universities, which are divided into academic, application and newly built universities. The first category of evaluation index system consists of 4 first-level indicators, 12 second-level indicators and 37 key audit points. The second category of evaluation index system consists of 7 first-level indicators, 27 second-level indicators and 78 key audit points. The first category of audit focus related to curriculum teaching is reflected in the "3.5 Excellence in Teaching", "3.5.2 Promote learning-centered, teacher-led classroom teaching reform, promoting the integration of information technology and teaching process, strengthening the construction of online teaching resources, and improving the advanced, innovative and challenging nature of the curriculum". The second category of audit focus related to curriculum teaching is embodied in "2.4 Classroom Teaching" in "2.4.1 Implementation of learning-centered, teacher-led classroom teaching and implementation of student learning results-oriented teaching evaluation". Both categories are guiding macro assessment, without in-depth evaluation and assessment.

University courses are usually composed of public basic courses, professional education courses and practical courses. The effect of curriculum teaching and learning greatly affects the quality of personnel training. It is difficult to accurately evaluate the teaching result of a course, which is affected by many factors and has the characteristics of coupling and hysteresis [4]. Regardless of how reliable and valid the evaluation instruments themselves are, the effectiveness of using evaluations as a measure of teaching quality is determined by the policies, processes, and practices implemented within an institution [5]. Just as Ornstein and Hunkins [6] said, “Evaluation ad-

dresses the value and effectiveness of curricular matters and activities. It centers on both teachers' and students' actions within the educational arena, primarily the classroom". "Much dialogue regarding evaluation seems to exist within clouds of fear, confusion, ignorance, myopic thinking, and of course, enlightened ruminations". "We should be mindful that evaluation not only assesses learning, but also promotes and nourishes it".

In order to improve the teaching and learning effect of courses, this paper proposes a probe evaluation method based on keypoints of knowledge, which is a dimension extension and beneficial supplement for Undergraduate Education Teaching Review and Evaluation (2021-2025). This evaluation method is also applicable to the self-evaluation of teachers' teaching effect and students' learning effect.

2 A probe course evaluation method

There are already differences among students who choose the same course, and this difference becomes more and more obvious with the increasing gross enrollment rate of universities. The evaluation methods of Undergraduate Education Teaching Review and Evaluation and China Engineering Education Certification are usually in the average sense of assessment in course evaluation, focusing on the teaching aspects (teaching syllabus, lesson plans, experts in the classroom, talking with students, teaching materials, hardware conditions, information level, etc.) and learning aspects (mid-term test, process check, final examination, comprehensive score, etc.). Kifle and Alauddin [7] found that assessments based on class averages masked heterogeneity within a student cohort.

The original meaning of a probe is a tool or device used to detect, test, measure, or monitor certain physical or chemical properties, usually consisting of one or more sensors and a data acquisition and processing unit. Probes can be used for a variety of applications, such as the detection of living organisms, monitoring environmental pollution, and testing material properties.

The probe course evaluation method is a deep detecting way based on the keypoints of knowledge in the course. As the investigators, experts conduct in-depth discussions and exchanges with individual, part or all students on specific keypoints of knowledge, and immediately detect the level that students can achieve in the knowledge points, so as to evaluate the students individually.

3 The hierarchical division of teaching and learning effect of university engineering courses

The university courses are the most basic unit to realize the talent training program and build the curriculum system. A course itself has theoretical diversity and practical richness, and is a dynamic educational existence composed of certain educational goals, specific knowledge and experience and expected learning activities [8]. Just as Jayne Bartlett [9] said, "the main feature of an outstanding lesson is that all students

make progress". As a teacher, it is difficult to make every student achieve the best. The teachers should not have a rough average understanding of the teaching effect, but should know the best and worst learning effect, and know the highest level that the students can achieve.

The teaching and learning effects of university engineering courses are divided into 9 levels, as shown in Table 1.

Table 1. The hierarchical division of teaching and learning effect evaluation of university engineering courses

Hierachy sequence	Hierarchy name	Feature description
1st	Perplexed level	The purpose of learning is unclear, the basic concepts are not clear, the basic knowledge of the course is lacking. No ability to use knowledge, and the student is wandering away from the course.
2nd	Specious level	The purpose of learning is not strong, the concept is specious, the knowledge is half-understood, the knowledge structure is lacking, and the knowledge application ability is insufficient.
3rd	Passed level	The course knowledge and application ability have just reached the passing level.
4th	Medium level	The course knowledge reached the medium level, with simple engineering application ability.
5th	Good level	The course knowledge has reached a good level, and the engineering application ability is good.
6th	Noticeable level	The course knowledge has reached a good level, and can organically link knowledge with engineering practice.
7th	Excellent level	The course knowledge and application ability reach excellent level, have the method and ability to solve complex engineering problems.
8th	Outstanding level	Excellent course knowledge and application ability, with good scientific literacy and thinking methods, able to propose creative methods in solving complex engineering problems.
9th	Remarkable level	Excellent course knowledge and application ability, with excellent scientific literacy and thinking methods, with the spirit of responsibility and lifelong learning consciousness, able to study and search in difficulties and loneliness.

4 The selection principle of key knowledge points in probe evaluation

The knowledge point is a concept or thought with independent and complete significance in the curriculum knowledge system. The selection principles of key knowledge point used in the evaluation of course teaching and learning effect are as follows:

(1) The knowledge that is fundamental or important.

(2) Definitions and descriptions are concise and clear.

(3) The concept is clear and unambiguous.
(4) Easy for in-depth discussion.
(5) Each chapter contains no more than two keypoints of knowledge.

Take the course of Mechanics of Materials [10] as an example, the following keypoints of knowledge can be selected: Tension or compression, shear, torsion, bending strength of beams, bending deformation of beams, combination deformation, the stress-states at a point, the stress-strain relationship of materials, engineering strength theory, buckling and stability of columns, geometrical properties of plane graph, the energy method, statically indeterminate structure.

5 The implementation method of probe evaluation

In the evaluation method proposed in this paper, evaluation experts are the most important factor, and the requirements for evaluation experts are as follows:

(1) Have systematic expertise, familiar with relevant engineering applications.
(2) Have wide range of knowledge, understanding of international cutting-edge technology.
(3) Familiar with modern design and analysis techniques, such as computer aided design, advanced experimental techniques and numerical simulation methods.
(4) Open-minded, inclusive and passionate about education.
(5) Familiar with the curriculum system of the major.
(6) Work rigorous and serious, strong sense of responsibility.

A keypoint of knowledge in the course is randomly selected, and the implementation of evaluation can be selected in one of the following two ways, the first one is preferred.

(1) Hosted by one or several evaluation experts, thematic discussions are held with students (single, group or all) in a free and relaxed environment. The evaluation level is like a crossbar in the high jump competition, students who do not reach the next level will get the current hierarchic level and exit the discussion. As the discussion deepens, the number of students participating in the discussion will continue to decrease, and eventually all the students participating will get the corresponding level.

(2) The questionnaire carefully designed by experts will be used to conduct the survey, which needs to be based on the existing face-to-face interview experience, to eliminate possible interfering factors and avoid possible omissions.

6 Two examples of the construction for probe course evaluation

Take two courses as examples to introduce the hierarchy construction of evaluation.

6.1 Bending strength of beams

The bending strength of the beam is chosen as the keypoint of knowledge in the course of Mechanics of Materials [10]. A brief introduction to the knowledge background: The bar with bending as the main deformation is called "beam", which can be seen everywhere in the engineering structure and is the main bearing member, such as the building beam, the crane girder, the train wheel shaft and so on. Road bridge plates, pressure vessel tanks, tall buildings, etc., and even the poles and sticks used for picking things, the mechanical model is also a "beam". The evaluation criteria for each level are listed in Table 2.

Table 2. Hierarchical division of the knowledge in bending strength of beams

Hierachy sequence	Hierarchy name	Criterion description
1st	Perplexed level	Lack of basic understanding of beam constraint and deformation characteristics, section geometry, bending moment, transverse shear force, bending stress and strength conditions, and lack of ability to solve practical engineering problems.
2nd	Specious level	No systematic cognition has been established on the constraint and deformation characteristics, section geometry, bending moment, transverse shear force, bending stress and strength conditions of the beam, and the ability to solve practical engineering problems is insufficient.
3rd	Passed level	He/She has a systematic understanding of beam constraint and deformation characteristics, section geometry, bending moment, transverse shear force, bending stress and strength conditions, and can complete beam strength design according to national and industry standards.
4th	Medium level	On the basis of the third level, he/she has preliminary scientific thinking. For example, he/she knows why rectangular cross-sectional beams used in construction are usually placed vertically with long sides rather than horizontally with long sides.
5th	Good level	On the basis of the fourth level, the engineering application ability is strong. For example, from the point of view of the force and material saving, he/she knows that there are better choices than equal section beams (hollow beams, "I" beam, "T" beam, etc.), and he/she can also recognize that theoretically there are better options such as variable cross-section beams.
6th	Noticeable level	On the basis of Level 5, the application of knowledge can integrate engineering and social factors. For example, in the design of building beams, factors such as mechanical behavior, space influence, manufacturing time and cost can be considered comprehensively to make a reasonable choice of program.
7th	Excellent level	On the basis of the sixth level, has the ability to solve unconventional problems. The energy principle can be applied to analyze the stress and deformation of the beam. For example, for complex structural beams (geometry, load, etc.), numerical simulation technology (such as finite element method) can be used for mechanical analysis to complete the strength evaluation.
8th	Outstanding level	Based on the above knowledge and ability, has the ability to solve engineering problems creatively. For example, he/she can propose a scientific, reasonable and reliable solution to the problem of how to use a 10-tons crane to lift 20 tons of heavy weights.
9th	Remarkable level	On the basis of the aforementioned knowledge and ability, he/she can go beyond the course itself, have a high level of understanding, be integrated, and take the project into consideration. Be able to apply the knowledge of beam mechanics analysis to special conditions (such as high temperature, low temperature, nuclear environment, outer space, living organisms, etc.), different scales (such as large tower, circuit board coating, etc.), non-static strength problems (fatigue, creep, etc.).

6.2 Working cycle of the piston compressor

The working cycle of the piston compressor is chosen as the keypoint of knowledge in the course of Pumps and Compressors [11]. A brief introduction to the knowledge background: Compressors are fluid machines that supercharge gas, and piston compressors have the strongest supercharging capacity of all types of compressors. The working cycle of the piston compressor refers to the intermittent working process of the gas from being inhaled to discharged in the cylinder, which is composed of four stages: suction, compression, exhaust and expansion. The evaluation criteria for each level are listed as follows (Table 3).

Table 3. Hierarchical division of the knowledge in working cycle of the piston compressor

Hierachy sequence	Hierarchy name	Criterion description
1st	Perplexed level	Lack of basic understanding of structure and characteristics, working principle and basic parameters of piston compressors, and has no ability to solve practical engineering problems.
2nd	Specious level	The structural composition and characteristics, working principle and basic parameters of piston compressor have not been established, and the ability to solve practical engineering problems is not enough.
3rd	Passed level	He/She has a systematic understanding of the structural composition and characteristics, working principle and basic parameters of piston compressors, and knows that the working cycle indicator diagram is *p-V* diagram (absolute pressure of working medium in cylinder vs working volume of cylinder), and can complete the thermodynamic design calculation by referring to relevant technical manuals.
4th	Medium level	On the basis of level 3, he/she has preliminary scientific thinking. For example, to understand why the actual cycle has one more expansion process than the theoretical cycle; Knows the true physical meaning of the volume coefficient.
5th	Good level	On the basis of level 4, the engineering application ability is strong. For example, for the newly designed piston compressor, knows how to pre-draw the working cycle indicator diagram; For existing piston compressors, knows how to measure the working cycle indicator diagram.
6th	Noticeable level	On the basis of level 5, engineering and social factors can be integrated into the application of knowledge. For example, if a gas is compressed, is it a one-stage compression, two-stage compression, or multistage compression? Able to make reasonable choices.
7th	Excellent level	On the basis of 6th level, the ability to solve unconventional problems is demonstrated. For example, it is possible to make a basic diagnosis of compressor operating faults according to the shape of the actual indicator diagram.
8th	Outstanding level	Based on the above knowledge and ability, have the ability to solve engineering problems creatively. For example, it is able to propose scientific and feasible solutions to the problem that the clearance volume of traditional piston compressors is difficult to avoid.
9th	Remarkable level	On the basis of the aforementioned knowledge and ability, he/she can go beyond the course itself, has a high level of understanding, be integrated, and take the project into consideration. The piston compressor working cycle can be studied more deeply (such as thermal analysis, air compression and expansion waves, air column vibration, real-time fault diagnosis and control, valve fluid-structure coupling, etc.). Ability to explore micro fluid machinery, extreme conditions applications, etc.

7 Conclusions

In the teaching practice of professional courses, the authors had tried to evaluate the level of some students using this method, and realized the following three advantages of this method:

(1) The construction process of the criterion for distinguishing the level of each key knowledge point is also a process to promote the continuous improvement of the teacher. It is necessary to study many aspects related to the course, so that the course content and teaching design can reach a higher level.

(2) In the course teaching, the feedback of some students' evaluation level results can make teachers instantly aware of the current teaching effect and make positive adjustments in time.

(3) The criterion of distinguishing the level of each key knowledge point is a good guidance direction for the overall development of students, which can significantly improve the efficiency of the teacher's guidance to students.

The in-depth exploratory teaching effect evaluation method based on keypoints of knowledge is complementary to the traditional course evaluation method and still needs to be improved continuously.

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