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Laboratory Pedagogy and Outcome Evaluation Based on OBE Concept

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Abstract. The essential requirement of engineering education certification is to establish the pedagogy and evaluation mechanism with OBE concept. This paper reviews the evolution of reforms on laboratory teaching modes and evaluation methodologies from the perspective of engineering education certification. It is suggested that OBE-based laboratory teaching should combine the successful practices of classic laboratory teaching modes with modern educational technology, implement diversified teaching mode, and highlight the application of differentiated evaluation methodology focusing on competence.

Keywords. OBE; Laboratory teaching; Outcome evaluation; Engineering education

1. Introduction

The primary task to fully recognize the concept of outcome-based education (OBE) and to implement the National Standard for Undergraduate Teaching Quality in Colleges and Universities is to achieve higher engineering education certification, which essential requirement is to establish the OBE oriented pedagogy and the evaluation mechanism, and to realize the transformation from curricula centered teaching design to outcome-oriented one under the concept of OBE. The key link of engineering education certification is evaluation, which is to establish a normalized evaluation system covering every teaching participant, and the evaluation results are used for continuous improvement. As engineering education shifts from a traditional content-based and time-based mode to a learner-centered outcome-oriented mode, more detailed and rigorous assessments of learning outcomes are needed. The objectivity, scientificity, accuracy and differentiation of evaluation has a close bearing on the construction of monitoring and guarantee system for teaching quality.

Laboratory teaching constitutes a vital part of higher engineering education, which has different characteristics and rules from classroom teaching. Under the background of engineering education certification, laboratory teaching faces many problems to be solved in data collection, outcome assessment and achievement analysis and calculation. It is of great significance to study the laboratory teaching modes and evaluation methodologies based on OBE concept.

2. Laboratory teaching based on OBE concept

2.1. Development trend of engineering education

Qin Zhu et al. [1] reviewed the four major areas of engineering education policy changes since China's reform and opening up, namely, institutional reform, disciplines and majors, training objectives, and curriculum reform. Reforms of the early Chinese engineering education reform from the Soviet model 'overemphasis on practice' to 'overemphasis on theory', then it is followed by a 'Plan for Educating and Training Outstanding Engineer' aimed to create a large number of new generation of engineers who can combine theory with practice through close integration of industry and education, heralding the transformation from a big country of engineering education to a strong country of engineering education. At present, China is trying to solve the problem of integrating into the global engineering education system, including joining the Washington Agreement and establishing its own engineering certification system to strengthen the international status and competitiveness of China's engineering education.

Nowadays, in context of the new round of industrial revolution, engineering education needs to deepen the reform of teaching content and curricula system, and the construction of new engineering discipline has been put on the agenda. The training mode of new engineering talents has two characteristics, namely general education in a broad sense and interdisciplinary/transboundary cultivation [2]. So firstly, it is necessary to speed up the transformation and upgrading of traditional disciplines, to expand the connotation and construction focus of traditional disciplines, and to create an upgraded version of traditional disciplines. Secondly, the integration of multiple disciplines and specialties should be promoted [2]. The challenge in engineering education is not only to equip students with technical knowledge, but also to develop judgment and sanity. Trained engineers should have six engineering thinking habits: problem-finding, creative problem-solving, visualising, improving, system thinking and adapting [3].

OBE education reform focuses on the required competence that students should possess after graduation, and all elements of the teaching system should be configured to help students acquire these competences. Therefore, the OBE emphasizes helping students achieve outcomes related to knowledge, skills and ideas by carefully organizing the structural elements and evaluation of each curriculum. In the traditional teaching and learning process, teachers just inform students what to do, and often focus on using fixed evaluation system to urge students to complete the learning tasks scheduled by the syllabus. However, The OBE concept emphasizes student-centered and outcome-oriented pedagogy under the guidance of teachers. The teaching process becomes more flexible, and students become more active in the learning process. Each student may have different learning paths to obtain the deserved outcome [4].

2.2. Reform of laboratory teaching mode

In the past, curriculum-centered teaching design dominated college laboratory teaching, which teaching content generally includes three levels of module such as 'basic experiment', 'comprehensive experiment', 'applied innovative experiment'. The problems of such teaching design manifest as follows: more traditional replication experiment, lack of innovation, lower difficulty, disadvantage in competence fostering, lack of progressive gradient or coherence or interdisciplinary integration. However, the OBE curricula system and teaching content are determined according to the requirements of post-graduation competence. The construction of new engineering discipline requires increase in difficulty of curriculum and improvement of interdisciplinary integration to conform to the emerging technological revolution. National University of Defense Technology strives to construct a persistent applied curricula system featured as 'interdisciplinary' and 'research methodology' implemented via 'blended learning' [5]. Nanyang Technological University (NTU) prepares students to enter the field of manufacturing engineering and semiconductor manufacturing through specialization, and incorporates emerging technologies such as nanomanufacturing into its curricula.

In addition to the traditional engineering training, all students experience the manufacturing enterprise scenario to strengthen the knowledge learned in class and improve their job aptitude after graduation [6]. In this situation, laboratory teaching should make a positive response to the changes brought by the emerging scientific and technological revolution by virtue of reforming the laboratory teaching mode actively and cultivating students' competence to adapt to the future job after graduation.

Despite of increased research-based experiments over the past 20 years, the traditional 'cookbook' mode of laboratory teaching, in which students follow a given procedure, remains a prominent feature of many undergraduate laboratory courses. The National Academy of Sciences and the American Association for the Advancement of Science proposed [7] that learner's frequent participation in practical research may favor undergraduate education in two ways: students' direct participation in laboratories, or the construction of research-based curricula that simulate research practices. It seems a feasible scheme to set up experimental curricula supported by teachers' scientific research projects. Problem-based learning and experiential learning are important components of higher education in the age of emerging scientific and technological revolution. Problem-based learning is student-centered, which key point is that students work in small teams to solve open problems. In particular, project-based learning has been proved to enable students to participate in experimental curricula more actively and effectively, which is conducive to the improvement of students' abilities [8].

For the new generation of students in 21st century, the traditional learning methods for engineering education are difficult to match the development of the times. Research indicates that blended learning, a teaching mode combining face-to-face instruction with online learning, has become a new trend in education. The new generation of students notably characterized as their close connection with information technology, and their learning styles differs to each other. In this context, universities are facing with the great challenge of how to improve students' learning quality. New technologies such as virtual reality environments, web-based learning platforms, robots, virtual labs and simulations, digital badges, mobile communication devices, game-based learning, social networks, internet of things, learning analysis systems, assessment and feedback tools have all been effectively applied to education [9].

3.Evaluation of experimental curricula

3.1. Conclusive evaluation

At present, the ubiquitous evaluation on 'classroom-style' laboratory learning is to summarizes and evaluates the learners' usual performance (experimental operation, lab report) or experimental test scores totally, which is a kind of final post-class assessment in essence. This evaluation method is characterized by high subjectivity, insufficient attention to the practical operating ability of students, lack of process supervision and feedback, inducing mutual plagiarism, and the consequence can neither reflect the real effect of laboratory teaching nor the actual competence of students [10]. In addition, students have no approach to prove that they have completed the make-up task in accordance with the requirements of the post-class feedback [11].

3.2. Process evaluation

The laboratory teaching evaluation mode based on process management is actually a process refined evaluation of a single experimental project with various links of learner's performance encompassed through some technical means [12]. The advantage of the process assessment is manifested as focus on the enthusiasm of students participate in the course, the ability of experimental operation and the ability of comprehensive application of experimental technology. Obviously, this kind of assessment method may be more suitable for replicate experimental projects with programmed procedures (so-called 'cookbook' experiments). Nonetheless, this evaluation process is time-consuming and does not reflect learners' independent creativity.

3.3. Performance evaluation

Performance evaluation should combine process evaluation with summative evaluation and increase the weight of process evaluation. Laboratory teaching based on performance evaluation inspects students' laboratory performance and pays attention to the whole process of experiment, which is reform of the conventional laboratory evaluation. The difference between performance evaluation and process evaluation lies in that the former can better reflect students' independent innovation. Its essential is that students are required to show their own learning process, or to show completing some experimental tasks using the knowledge and skills they learned. The evaluation is made by observing the learner’s practical operation or continuously recording their phased achievements. It is a straightforward method to measure students' ability to use knowledge comprehensively to solve practical problems. It highlights practicality, processing, developing and humanization in operation. Implementation of performance evaluation requires teachers firstly establish the evaluation content and learning goals, setup performance tasks, and then make the assessment according to the standard ability, proficiency and independent ability to complete tasks [13]. Performance evaluation has disadvantages such as passive learning, strongly deliberate performance, on spot timeliness, and long process continuity.

3.4.Formative evaluation

The formative evaluation system of experimental curriculum is the whole evaluation of the process assessment throughout an experimental curriculum, and it is the dynamic evaluation system of all-round and overall-process assessment of learner' performance. Formative evaluation can help students change learning model, improve learning effect, promote integrated development, make full use of teaching resources and improve teaching quality. However, formative evaluation also has many problems, for example, teachers need to organize evaluation activities periodically giving rise to heavy workload and cumbersome feedback [10]. Blended teaching reform that integrates traditional classroom teaching (offline) with online curriculum learning (online) can be explored, and formative evaluation system can be introduced into the evaluation process. System grades automatically according to the student participation and online task completion. Meanwhile, A formative evaluation online platform can be set up to conduct a statistical analysis of the evaluation results in lab performance, experimental completion, theoretical examination and operation test to realize the fusion of teaching evaluation and network technology, playing the role of evaluation feedback [14]. Formative assessment is an interrelated process, which enables students to timely narrow the gap between their ability and expectation level through experimental activities. One of the characteristics of formative evaluation is that students can participate in self-evaluation. Students set the assessment goals of the experiment and are required to compare the completed experimental content with the assessment criteria and make continuous improvement, so as to cultivate the ability of self-supervision and to perfect it through continuous self-improvement [11].

3.5.Outcome oriented evaluation

The so-called outcome is the measurements of students' knowledge, skills and attitude. OBE evaluation requires quantitative measurements of curriculum learning outcome and graduation outcome at the level of curriculum modules and graduation requirements respectively, so as to evaluate whether students’ outcome meet graduation ability requirements [15]. The existing problem of laboratory teaching is that the actual assessment requirements do not match the curriculum objectives, including the content and assessment method lacking clear requirements and too simplex evaluation means used. Assessment results without supporting criteria fails to prove the curriculum objectives are achieved and cannot truly reflect the students' ability. The key solution to the existing problems relies on collecting evaluation evidence and combination of various evaluation means.

Competency-based evaluation needs to establish feasible evaluation models, which strive to shift the focus of evaluation from the assessment of final results to that of competence formation. This evaluation requires incorporating elements reflecting ability into the evaluation framework and quantitative assessment based on ability and outcome should be conducted using 'hybrid' method [16]. E.S.Holmboe et al. [17] believe that the constituent characteristics of an effective competency-based assessment system should include: (1) more continuous and frequent assessment (2) criterion-based assessment using a developmental perspective (3) Competency- and work-based assessment emphasizing the ability after graduation (4) assessment tools that meet minimum standards of quality (5) more 'qualitative' approaches incorporated to assessment (6) wisdom of a group and active engagement that the trainee involved. Under the concept of OBE, educational evaluation has changed from teaching effect to learning effect, and the traditional teaching based on curriculum content has changed to the cultivation process based on outcome demand. The content should reflect the progressive difficulty, which is conducive to the competency-based outcome evaluation. Outcome evaluation should first segment the learning content, such as the three-tiered training level proposed according to the requirements of engineering education certification, including the basic skills level, the comprehensive application ability level and the engineering practice and innovation ability level. For all levels, diversified assessment methods should be explored from multiple perspectives [18]. OBE assessments can take the form of exams, lab operations, assignments, lab reports, and case studies, all of which can be examined through curriculum testing to determine whether students are achieving learning outcomes. In general, OBE involves three main outcomes, all of which are related to different curriculum evaluations: program outcomes, curriculum learning outcomes, and course assessments. Each course in the training plan has its learning outcome and course assessment methods, and each learning outcome corresponds to different requirements of program outcome. The calculation of program outcome is obtained through course assessment, so the learning outcome and program outcome are derived from the direct measurement of the course. In order to obtain the measured values of learning outcome and program outcome, two matrices must be formed: one is course assessment-learning outcome matrix, the other is learning outcome-program outcome matrix. These matrices show the mapping between all course assessments, learning outcomes, and program outcomes. Course assessment marks are used to calculate the measurements of learning and program outcomes: each course assessment is linked to different learning outcomes as denoted by a coefficient matrix, and learning outcome is linked to program outcomes through another coefficient matrix. Therefore, the learner's measurement of learning outcome or program outcome is the direct result of his marks throughout the course and is distributed according to the coefficient matrix [4].

To assist teachers in OBE assessment and implementation of continuous improvement, a final assessment tool should be developed, which can be a macro functional package that automatically calculates learner's individual learning outcome and program outcome grades based on their module assessment marks. The results of all modules calculated by the assessment tool will be saved in the learner's learning outcome or program outcome database and generate class and individual exit outcome. The curriculum assessment results calculated by the assessment tool provide a variety of results describing students' learning outcome, which can generate periodic outcome data of all students for continuous improvement [15].

Digital badges, a new thing in the age of information technology, are a way to showcase a learner's acquired competence. Digital badges allow teachers to create measurable lesson outcomes and to clearly track tasks and activities completed by learners. Digital badges can both evaluate traditional learning outcomes and validate the learning process, thus offer the potential for a real and direct assessment of laboratory skills. Badges bear specific information including publisher, standards and evidence metadata. Evaluations of activities associated with obtaining badges must be inferred based on evidence-based knowledge, skills and attitudes so that digital badges are representative of a learner's learning outcome. Digital badges use the following evidence content as a basis for evaluation: what are the knowledge, skills, and attitudes connected to laboratory course that should be assessed, and what tasks would allow a student to demonstrate those constructs? In practice, this evidence content can be established in three steps: collection of student work/artifacts, evaluation of the work/artifacts relative to agreed upon criteria that are grounded in analysis and modeling of the domain, and creation of inferences based upon the quality of the student’s work. Purdue University has developed and launched a learning management system called Passport1 in the U.S. It uses an open badge framework system that allows teachers to create, evaluate learning tasks and issue digital badges based on student’s achievement. Students operate according to the requirements of the experiment, using their own shooting tools (such as mobile phones) to shoot videos showing their own operations and then upload them to the management system. The teacher will give feedback to the students after watching the video to make assessment and suggestions [19]. The digital badge learning evaluation needs to build an intelligent learning platform, and the online MOOC curricula of some universities can be used as the digital badge online learning platform. In addition, teachers need to fully consider the evaluation characteristics of the curricula to carry out detailed information-based teaching design [20].

3.6.Fuzzy synthetic evaluation

Fuzzy synthetic evaluation method can also be applied to the evaluation of laboratory course, and the fuzzy system is designed to match the traditional outcome, which provides a new method for evaluation and measurements based on OBE concept. Fuzzy measurement is based on approximate reasoning, which considers the membership degree of input measurement value and has more flexibility compared with traditional reasoning method. Fuzzy evaluation can set rules, link all assessment marks to the final outcome measurement, and reset the rules according to the student's ability or the difficulty of evaluation. In general, the traditional outcome is measured by fixed metrics (or weights), while this fuzzy reasoning model provides a synthetic consequence of both quantification and qualification. The qualitative and quantitative indicators of outcome have been listed as one of the basic criteria for outcome evaluation by the Council of Higher Education in the United States [4]. When the fuzzy synthetic evaluation method is used to evaluate the outcome of experimental courses, the evaluation factors and evaluation grade of the evaluated object are determined first, then the evaluation matrix is formed and the weight of each factor is determined. Finally, fuzzy synthesis is carried out to obtain the synthetic results of fuzzy evaluation and make corresponding decisions. Fuzzy synthetic evaluation has good evaluation effect on multi-factor and multi-level complex problems, and has unique evaluation value for the evaluated object, which is not affected by the assemblage of the evaluated object [21].

It has been a short time since China joined the Washington Agreement, and many universities' work on engineering education certification is still at the initial stage. In the context of new engineering faculty, the outcome evaluation of engineering education is facing with many challenges: (1) many traditional laboratory item is not conducive to train students' ability to solve engineering problems due to lack of depth and breadth, less interdisciplinary, discontinuity causing deviation from the requirement of the engineering education certification. (2) The teaching mode is simplex and short of application of modern educational technology that students are willing to accept in the information age, so it affect effective evaluation and provide limited evidence sources for outcome evaluation. (3) The unscientific evaluation method with poor compatibility between qualification and quantification gives undifferentiated evaluation results. (4) simple evaluation and analysis tools leads to subjective and arbitrary assessment results.

4. Summary

Engineering education certification facilitates the development of new engineering discipline, which key point is to establish teaching modes based on OBE concept and evaluation mechanism conducive to continuous improvement. Laboratory teaching, as an important part of new engineering education to cultivate the ability to solve engineering problems, should be taken seriously by dealing with the dialectical relationship between tradition and innovation. It is necessary to integrate and modify the classical experimental items, extensively absorbing knowledge reflecting the forefront of current

science and technology, enhancing the generalization and interdisciplinary, combining the successful practices in the conventional laboratory teaching mode with modern educational technology.
Teaching content, pedagogy and evaluation method and evaluation tool should be orchestrated to establish differentiation-based OBE evaluation system of laboratory teaching, highlighting the mutual relationship between them and integrating the four into experiment teaching design. Additionally, The competence-based differentiated evaluation should be enhanced to improve the differentiation and objectivity of assessment consequence to meet the evaluation requirements of OBE concept. Meanwhile, information evaluation means and modern statistical analysis tools should be adopted to serve the quantitative evidence collection and the evaluation of engineering education certification.

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Conflicts of Interest
The author declares that there is no conflict of interest.

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