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Exploration and Practice of the OBE-CDIO Integrated Model in the Course Development of Introduction to Biomedical Engineering

Yubo Liu^{1,*}, Boyu Si¹ and Lijun Hao¹

¹ School of Medical Instrument, Shanghai University of Medicine & Health Sciences, Shanghai, China

* Correspondence: Yubo Liu, School of Medical Instrument, Shanghai University of Medicine & Health Sciences, Shanghai, China

Abstract: Based on the challenges identified in the Introduction to Biomedical Engineering course, including the fragmentation and excessive breadth of its knowledge system, the disconnect between theory and practice, and students' insufficient practical engineering competence, this paper constructs a teaching reform scheme that integrates the OBE and CDIO frameworks. Grounded in industry talent demands and program graduation requirements, the scheme adopts a backward design approach to formulate course-level objectives and stage-specific project goals. It takes the full-process production of dental implants as a case study, embedding OBE and CDIO principles into every stage of the project-based practice. A tripartite evaluation system is also incorporated, combining instructor assessment, student self-assessment, and peer evaluation. The cross-validation among these three forms of assessment enables dynamic feedback and continuous improvement throughout both the teaching process and the learning outcomes. Practice demonstrates that this reform scheme effectively bridges the gap between theoretical learning and engineering practice, thereby providing an actionable pathway for the systematic reform of multidisciplinary engineering courses.

Keywords: OBE; CDIO; Biomedical Engineering; Dental Implants; Blended Teaching Reform

1. Introduction

In the context of the new technological revolution and industrial transformation, engineering education in China has entered a stage centered on quality improvement. As a systematic and comprehensive transformation of the national innovation system and the economy and society, the development of new quality productive forces has placed higher demands on the supply of high-quality engineering talent. Against this backdrop, the Ministry of Education has set higher requirements for cultivating outstanding engineering science and technology talent, explicitly orienting talent cultivation toward industry needs and interdisciplinary integration, and strengthening engineering practice capabilities, ethical literacy, and innovative thinking. The comprehensive upgrading of these cultivation requirements has made it increasingly urgent to reform teaching models in biomedical engineering courses, which are characterized by interdisciplinary integration.

In recent years, Outcome-Based Education (OBE) has attracted considerable attention in engineering education [1]. This concept takes the competencies that students ultimately acquire as intended outcomes and uses them to design the entire teaching process in reverse, thereby effectively improving the quality of engineering talent cultivation. However, although OBE clarifies intended outcomes, it lacks specific operational plans for instructional design and implementation pathways. The CDIO (Conceive, Design, Implement, Operate) teaching model precisely fills this gap [2]. Since its introduction in 2004, CDIO has developed a practical framework based on the full life

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cycle of projects. By enabling students to experience the four stages of Conceive, Design, Implement, and Operate, it provides actionable implementation plans for achieving outcomes. The integrated OBE-CDIO model has gradually become a mainstream trend in current engineering teaching reform because it uses OBE to anchor a clear outcome orientation and CDIO to establish a solid implementation pathway. The two models are not simply superimposed; rather, they make outcome orientation and implementation pathways complementary, thereby effectively improving the quality of cultivating outstanding engineering science and technology talent.

Based on the integrated OBE-CDIO model, this paper addresses the current dilemmas faced by the Introduction to Biomedical Engineering course and constructs a multidimensional evaluation system covering learning ability, practical innovation ability, and teaching feedback. At the same time, it uses a full-process dental implant project as a practical case of this integrated model and clarifies the objectives and implementation pathway of the project to meet the demand from industry for cultivating outstanding engineers. It also continuously optimizes the teaching model based on teaching feedback, thereby providing a valuable reference for teaching decision-making.

2. Current Status and Challenges of the Introduction to Biomedical Engineering Course

As the first professional orientation course encountered by first-year undergraduates majoring in biomedical engineering, this course plays a key role in broadening the professional horizons of students and igniting their enthusiasm for learning. However, in actual teaching practice, this course has exposed a number of shortcomings. On the one hand, its knowledge system spans multiple disciplines, including mechanical engineering, materials science, clinical medicine, and bioengineering. It features broad content coverage, prominent interdisciplinary characteristics, and a general emphasis on theoretical exposition [3]. At the same time, first-year undergraduates often have to cope with multiple foundational courses in the same semester, resulting in considerable academic pressure. Faced with such a vast and complex body of knowledge, many students can gain only a superficial understanding and find it difficult to establish a complete knowledge framework. On the other hand, classroom teaching is still dominated by one-way lecturing by teachers, and teaching methods remain relatively monotonous. There is an obvious disconnect from the industry contexts of future employment for students, and students generally show limited willingness to participate actively in class. There is also a deeper issue that cannot be ignored: technological innovation in biomedical engineering proceeds at a very rapid pace, far exceeding the cycle of textbook revision and reprinting. As a result, what students learn in class often lags behind current developments at the industrial frontier, and practical teaching has therefore created a considerable gap between theoretical instruction and real industry needs. These combined factors have greatly diminished the actual effectiveness of this course, which should have served the role of professional enlightenment and foundational preparation. There is thus an urgent need for systematic optimization and reform in teaching methods, the arrangement of knowledge content, and practical training.

3. Course Reform Strategies Driven by the Integrated Obe-cdio Model

3.1. Course Design and Implementation Pathway

Based on the OBE teaching philosophy, the course objectives are formulated according to industry talent demands and program graduation requirements, aiming to cultivate interdisciplinary professionals who possess professional depth, an interdisciplinary vision, and clinically oriented thinking [4]. The cultivation objectives are decomposed level by level into quantifiable and attainable course objectives and phased objectives, so that every teaching activity has a clear outcome orientation. In terms of organizing teaching content, frontier industry developments and real engineering cases are introduced into the classroom to ensure that theoretical instruction always revolves

around actual engineering problems. Taking the chapter "Biomedical Materials" as an example, medical devices such as dental implants and abutments are made of biomedical materials, and their research, development, and production involve key technical steps such as material selection, mechanical design, surface modification, and biocompatibility evaluation. The phased project training objective can be set as the full-process development of medical device-related products. The theoretical knowledge and engineering experience that students accumulate while completing this project can be directly transferred to actual work in medical device-related positions, providing substantive competency support for employment in this field after graduation.

During implementation, with the phased objectives preset by OBE as the anchor and the four CDIO stages as the implementation framework, students work in project teams and, around the established objectives, go through a complete project cycle from needs analysis (Conceive), scheme design (Design), product development or simulated implementation (Implement), to outcome presentation and evaluation (Operate) [5]. In this way, the advancement of each task directly points to the achievement of the preset learning outcomes. Compared with the traditional one-way knowledge transmission model, the combination of OBE-based precise objective setting and CDIO-based project-oriented implementation can guide students to build a knowledge system while independently solving practical problems, ultimately providing industry and enterprises with interdisciplinary engineering talent who have a solid professional foundation and practical capabilities.

3.2. Tripartite Teaching Evaluation System

To effectively verify the actual effectiveness of the integrated OBE-CDIO teaching model, this course has established a tripartite evaluation and feedback system composed of teacher evaluation, student self-assessment, and group peer assessment. Specifically, teacher evaluation is mainly conducted against the teaching objectives preset by OBE, assessing knowledge mastery and project completion quality to ensure that each score corresponds one-to-one with specific indicator points in the graduation requirements. Student self-assessment focuses on guiding learners to review their own learning process and examine the growth and shortcomings they have experienced in solving problems [6]. Group peer assessment focuses on the team collaboration awareness and communication skills of each member during the advancement of the CDIO project. The three evaluation perspectives have different emphases and complement each other, effectively compensating for the subjectivity and one-sidedness that a single evaluation source can easily introduce, and making the final evaluation conclusions more comprehensive and credible.

The ultimate purpose of evaluation is to drive continuous improvement in teaching [7]. To this end, teachers flexibly adjust subsequent teaching arrangements according to the actual outputs of each project stage and provide targeted reinforcement of key and difficult content. At the midpoint of the course, anonymous questionnaires are administered to solicit student perceptions and specific suggestions regarding the arrangement of instructional content, the difficulty level of project tasks, and their experience of group collaboration. After the course concludes, focus group discussions are held to obtain student judgments on whether the course objectives have been achieved and their views on the evaluation mechanism itself. This feedback is systematically compiled and analyzed, and then used to revise and improve the teaching plan and evaluation criteria for the next cycle, thereby steadily enhancing teaching quality through a continuous dynamic loop.

3.3. Analysis of Talent Cultivation and Innovation Pathways under the Integrated Obe-cdio Model

OBE and CDIO are not simply superimposed on each other; rather, they are complementary in educational philosophy and implementation pathways. OBE addresses the question of "what kind of talent should be cultivated," taking industry needs as the ultimate goal and using backward design to determine cultivation objectives and

evaluation criteria. CDIO, by contrast, addresses the question of "how to cultivate such talent," using engineering projects as carriers, breaking down real engineering projects within the course for hands-on implementation, and enabling students to accumulate experience through practice. This integrated model transforms traditionally vague teaching objectives into quantifiable, assessable, and precise indicators; uses specific engineering projects as the main thread running through the entire course; and shifts instructional evaluation from a single focus on examination results to multidimensional assessment that combines process and outcomes. It thus shifts the focus of engineering education from "what teachers have taught" to "what students have learned and can do." In real engineering projects, students learn by doing, consolidate foundational knowledge, and enhance their engineering practice capabilities, teamwork, and innovative thinking. Moreover, this integrated model enables students to accumulate industry-relevant engineering experience in advance, allowing them to quickly adapt to job requirements after graduation and enhance their core employment competitiveness. It can therefore be seen that this model provides both clear objectives for engineering education and an actionable practical pathway for high-quality talent cultivation.

In implementation, innovative pathways for this integrated model can be explored from the following three dimensions. First, the curriculum system should be adjusted and optimized. Starting from industry needs, talent cultivation objectives, course objectives, and unit objectives are derived backward, so that theoretical teaching always revolves around engineering problems and the organic connection between theoretical knowledge and practical operation is strengthened. Students further internalize knowledge while solving real engineering problems, and their learning outcomes are quantitatively assessed. Second, the engineering education system should be innovated to accommodate multidimensional objectives. This integrated model breaks through the limitations of single technical competency cultivation in traditional engineering education and integrates multidimensional process objectives from real engineering practice into instructional design, thereby promoting comprehensive improvement in the overall abilities of students. Teaching methods have also gradually changed: project-based learning places students in the leading role, enabling them to learn by doing and then reflect on what they have learned. A multidimensional engineering education system requires a matching diversified evaluation system, including comprehensive multidimensional assessment of process, outcomes, and feedback, so that every aspect of competency cultivation is evidence-based. Third, the intrinsic potential of students for autonomous learning should be deeply stimulated. OBE establishes the central role of students, requiring them to actively participate in learning and ultimately complete project outcomes, while CDIO provides a vehicle for autonomous learning. When encountering uncertain engineering problems, students are compelled to proactively consult relevant materials, independently devise solutions, and solve problems either independently or through teamwork. The synergy between the two often generates a "1+1>2" motivational effect, effectively promoting the development of comprehensive qualities of students, stimulating learning autonomy and sustained learning motivation, and ultimately enhancing their overall competencies.

4. Practice of the Integrated Obe-cdio Model: A Case Study of the Dental Implant Project

In this course, biomedical materials, as a core knowledge point, have become a teaching difficulty because of the wide variety of materials and their significant differences in properties. To address this, relying on a school-enterprise cooperation platform and using the full process of dental implants from preparation and processing to final production as a carrier, the nine major process stages were introduced into teaching practice. According to the OBE outcome-oriented philosophy, students were divided into nine groups, each embedded in one of the nine major process stages of dental implants, and they conducted learning around two overall objectives: first, to systematically master the full-process production technology of dental implants and the

key technical points of each stage; second, to develop engineering practice capabilities in standardized operation, quality inspection, and cross-group collaboration in a real production environment.

4.1. Needs Analysis and Standard Cognition (Conceive)

Centered on the core concept that dental implant quality is designed in and runs through the entire process, instruction first guides students to develop a systematic understanding of the product life cycle before entering specific operations. This stage unfolds around three progressively advanced knowledge dimensions. The first is to understand the clinical functional requirements and human safety requirements of dental implants as Class III medical devices. The second is to master the national standards and industry specifications on which raw material grades, surface treatment process parameters, and mechanical performance indicators are based, covering technical documents such as GB/T 13810 and ISO 14801. The third is to clarify the logical relationships among the nine major processes, covering the complete production closed loop from raw material receiving, precision machining, surface treatment, performance verification, and sterility assurance to the finished product. Before formal operations, students in each group also need to complete a process flow chart for this stage and identify the quality control points, thereby forming an overall grasp of the full process and establishing a clear cognitive foundation for subsequent practical operations.

4.2. Formulation of Process Plans and Quality Control Standards (Design)

After clarifying the position of their own stage in the overall process and the interface relationships with upstream and downstream processes, each group formulates specific operation plans and quality control standards around their respective process tasks. The machining group compiles a machining process card according to the clinical design requirements for key geometric features of the implant; the mechanical performance testing group formulates a test plan according to relevant standards such as ISO 14801; the sandblasting group and the acid etching group determine the process parameter ranges for surface roughening and activation treatment, respectively; the sterilization inner packaging and outer packaging group formulates operation plans for inner packaging sealing and outer packaging as well as a package integrity verification plan according to standard requirements such as GB/T 19633.1-2024; the water quality sampling inspection group formulates an inspection plan and acceptance criteria according to process water standards; and the sterilization-related group formulates a sterilization process validation plan and packaging and sealing operation specifications. The process plan of each group must specify the critical control points and acceptance criteria for its own stage.

4.3. Job Rotation Operations and Process Implementation (Implement)

The nine groups of students correspond respectively to the nine major process stages and complete the standardized operations of their own stage in sequence. After the first round of fixed process operations is completed, a job rotation mechanism is launched. After each rotation, students reflect on the interface relationships between the new position and previous positions and understand how deviations in a given process are amplified through multiple processes and ultimately affect final product performance. Through the cycle of reflecting during operation, adjusting after reflection, and operating again after adjustment, students gradually integrate their partial understanding of each process through repeated operation and reflection, thereby forming a systematic understanding of the full-process production of implants.

4.4. Inspection, Verification, and Formation of Holistic Understanding (Operate)

After students have successfully completed the operational tasks of each process stage and achieved the objectives preset for each stage, they enter the concluding stage of the CDIO full-process practice framework, namely verifying the overall performance of the product and conducting quality evaluation. This stage includes three core tasks that advance progressively. The first is to summarize and integrate the inspection data and

quality control records accumulated in the previous nine stages and, on this basis, write a comprehensive performance analysis report on the finished dental implant. The second is to determine, by combining the data obtained from mechanical performance testing and the observation results of surface morphology, whether the product meets the safety standards required for clinical implantation. The third is to systematically sort out the quality control data of each process stage, with the aim of identifying the key variables that have a major impact on product quality and, accordingly, proposing targeted process optimization suggestions. During implementation, the entire class is simulated as a production workshop, and each group assumes a different process position. At the same time, strictly referring to the relevant provisions on document traceability in the ISO 13485 quality management system, students carefully complete operation records and inspection reports for each step. After the data of all groups are summarized, a complete batch quality file for the dental implants is ultimately formed. Supported by the phased objectives set by OBE and the CDIO full-process practice framework, students not only accumulate solid practical experience in data analysis and cross-group collaborative integration but also achieve effective improvement in their comprehensive competencies.

4.5. Tripartite Evaluation and Competency Feedback

Based on the nine sub-objectives preset by OBE, the teacher scores the process plan, operation records, and finished product analysis report submitted by each group item by item, focusing on the achievement of critical control points in each stage and the performance compliance of the final product. Student self-assessment focuses on the depth of understanding of individual students regarding process interface relationships during job rotation and the quality of their reflection on the causes of quality deviations. Group peer assessment takes the accuracy of information transfer and the standardization of data interfacing in cross-group collaboration as observation points to evaluate the communication efficiency and sense of responsibility of the team in a simulated production environment. After the tripartite evaluation data are summarized, a comprehensive competency feedback report for each group is formed, which not only presents their strengths and weaknesses in this stage but also indicates the directions that need to be strengthened in subsequent learning. Based on the evaluation results, the teacher provides centralized comments at the reflection seminar at the end of the course, conducts root cause analysis of common problems, and gives targeted guidance on individual problems, thereby quantifying performance in project practice into traceable learning evidence. In this way, teaching evaluation no longer remains at the level of scores but truly becomes a reference yardstick for the competency progression of students.

5. Conclusion

To address the teaching challenges in this course, this study proposes an integrated teaching reform plan based on the OBE philosophy and the CDIO engineering education model. This plan takes the learning outcomes preset by OBE as its starting point, adopts the full project life cycle of CDIO as its implementation strategy, and introduces a tripartite evaluation system to comprehensively assess the teaching process and outcomes. Project-based teaching centered on the full-process production of dental implants provides students with authentic and coherent engineering practice scenarios. Through a job rotation mechanism and reflective learning, students gradually construct a systematic cognitive framework that progresses from local proficiency to holistic understanding during dynamic operations. The tripartite teaching evaluation system, which runs throughout the entire project implementation process, serves as the key to ensuring teaching effectiveness and provides reliable data support for continuous improvement. In summary, the integrated OBE-CDIO teaching strategy offers a replicable empirical reference for overcoming the teaching bottlenecks of interdisciplinary engineering courses and cultivating interdisciplinary engineering talent with both professional depth and practical capabilities. It also provides a useful exploration for deepening engineering education reform in the context of Emerging Engineering Education.

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