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Application Research of CDIO Education Initiative in Reforming Online-Offline Hybrid Teaching of "Software Testing" Course*

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***Abstract*—CDIO is an innovative educational concept used around the world to improve the quality of undergraduate engineering education. It is very suitable to be applied to guide the teaching reform of software testing course, which is an important part of software engineering education. Due to problems like the lack of practice in traditional software testing teaching and that of students' interest in learning, we proposed a novel CDIO-based online-offline hybrid teaching reform model for software testing course. In this reformed teaching model, guided by the CDIO educational initiative, we redesigned the course structure to adjust the teaching content, developed multiple online course practice trainings in an online curriculum resource library, and built a teaching evaluation mechanism corresponding to case-based offline teaching. This teaching reform, to a certain extent, has achieved the goal of strengthening practice, enhancing students' interest in learning, and improving their professional quality and software testing skills. This teaching practice provides reference and inspiration for the innovation and reform of software engineering education in colleges and universities.**

Keywords—CDIO education initiative, software testing, online and offline hybrid teaching mode, teaching reform, application and research

I. INTRODUCTION

At present, with the drastic growth of large-scale complex software, software enterprises require a large amount of talents who are competent in test software, so that software products can be tested adequately and effectively before they are put into use, assuring the quality of software products. As a result, the demands for advanced testing talents increase obviously. Excellent talents are vital for the rapid development of software enterprises, which requires the educators of college and university reform their teaching and practice program to meet the demands. Moreover, the rapid development of Internet technology provides the technical supports for curriculum reform of software testing in higher education institutions.

Software testing is one of the significantly basic course for software engineering major, featuring more categories of testing technology, more testing tools and strong engineering[1][2]. Traditional teaching modes of the course usually expose many problems like lack in testing practice and low interest in learning[3][4][5], and the mismatch between the existing goals of curriculum and requirements of software industry[1], etc.. CDIO[6][7]is an innovative educational framework suitable for engineering education, which is recognized by the world. It has been successfully applied in many course teaching reforms in engineering education across many disciplines and majors to improve the quality of teaching, and it ranges widely from software engineering[8], mining engineering[9], applied logistics[10], chemistry[11], mechanical engineering[12] and electrical engineering[13][14], electronics[15], automation[16] and applied physics[17] to medicine[18], etc.. Therefore, we apply the CDIO educational theory combined with the online-offline hybrid teaching mode to carry out the teaching initiative practice of software testing courses, studying the effect and significance of CDIO on the quality of course teaching, and providing reference and inspiration for the innovation of engineering education in colleges and universities.

Some studies have been made to introduce CDIO framework to the teaching of software testing course[19][20][21]. In [19], Shi and Song applied CDIO to curriculum teaching of software testing, and they proposed a test technical ability training mode, constructed the learning managed system, referred to as networking training platform or online training platform, and finally, their teaching mode solve some problems in teaching of software testing to some extent. However, they spent several years(at least five or six years) in constructing their online training platform, and their platform can not be universally applied by others. In contrast, our course reform model is based on CDIO framework, and constructs online teaching practice on the base of a mature network practice teaching Website——"Educoder.net" , which is available for most universities of China. We have developed three basic types of testing practice: White-box testing, Black-box testing and Unit testing, and some featured practice testing trainings are available on the "MoocTest" platform, the detailed information will be described in section V.A. Jia and Yang[20] proposed the method of abiding by CDIO theory to combine practice teaching into classroom testing. Particularly, they adopted student-centric style and project-based teaching. Guided by CDIO theory Zhang and Wang[21] integrated case teaching, project-based learning and inspired learning into traditional classroom teaching to reform the software testing curriculum. Finally their reform had been proved to have positive results. Neither [20] Nor [21] did research on software testing curriculum reform based on CDIO with the help of online platform. By comparison, we make fully use of the existing online

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teaching and practice platform to strengthen undergraduates testing practice, and promote their testing skills.

The structure of the rest paper is organized as follows: CDIO educational initiative will be discussed in Section II. Our CDIO-based online-offline hybrid teaching reform model will be presented in Section III. From Section IV to VII, we will discuss the four parts of our reform model in detail. Section VIII presents our improvements in practices of course reform. Finally, Section IX concludes the paper and point out the future work.

II. CDIO Engineering Education Theory

A. Overview of CDIO Initiative

CDIO[6][7] is an innovative education framework aiming to promote the quality of undergraduate engineering education, proposed by the Massachusetts Institute of technology(MIT) of USA, and three Swedish universities, Chalmers universities of technology, the Royal Institute of Technology(KTH), Stockholm, and Linköping Universities(Liu) in 2003 after four years of close collaboration. In order to cultivate a new generation engineers, it adheres to the educational ideology of strengthening engineering foundation and integrates real-world systems and products into engineering education, the core of this initiative is to train and improve the level of students' theoretical knowledge and professional quality from mainly four aspects: Conceiving, Designing, Implementing and Operating, during which process the students are also cultivated to make personal contribution in collaboration and so is effectively improved the quality of undergraduate engineering education.

CDIO initiative provides solid theoretical support for the undergraduate education reform of engineering majors in colleges and universities, emphasizing the goal of cultivating students' engineering practice skills, independent learning ability, and professionalism. It guides the engineering education practice through four stages. First, the Conceiving stage is to define the system to be implemented and the required technology with the enterprise strategy and rules taken into consideration. Students learn the basic concepts, knowledge structure and business cases, so as to lay a solid foundation for the following Designing stage; then the Designing stage focuses on the design of the system and product which are described with drawings and algorithms; then the Implementing stage transforms the design into products through manufacturing, encoding, testing and validating; the final Operating stage puts the implemented product into use to turn it into the profit which means to maintain and improve it during operation until the system is not to be used.

B. The Implementation of CDIO Theory

When applying CDIO educational theory into the practice of engineering education, it can be implemented in four facets[6]: the first is to reform curriculum, that is to frame out the suitable curriculum to ensure that students learn theoretical knowledge and skills well, so as to promote their competence in constructing and designing the complex systems and products; second to improve teaching ability, so that students thoroughly understand technical information and master technical skills; the third requires laboratories and workshops to provide the an experiential learning environment and a practical platform to facilitate learning and practical experience; the fourth demands effective evaluation tools and methods to be designed and developed to help students assess their achievement and enhance learning effects.

CDIO engineering education initiative has been successful in engineering education in multiple disciplines and majors. This paper combines it with mature network technology to reform the teaching of software testing course, through which a teaching reform of online and offline blended software testing courses based on CDIO concepts is designed and implemented.

III. Our CDIO-Based Online-Offline Hybrid Teaching Model of Software Testing Course

The basic theory of our teaching reform model is CDIO theory. Simultaneously we combine Internet technology into offline classroom teaching, effectively solves problems existed in the curriculum teaching.

Our reform teaching model will be described from four aspects (as shown in table I): the first is about curriculum structure and design, the second is regarding to teaching and learning, the third concerns laboratories and workshops, and the fourth is evaluation in the course of teaching. Table I briefly lists the teaching design, and the details will be introduced one by one in the following four sections.

TABLE I
SUMMARY OF OUR TEACHING REFORM MODEL OF SOFTWARE TESTING BASED ON CDIO

	CDIO Theory	Reformation Contents
Curriculum	Models for curriculum structure & design	1.online resource library 2.lectures on industry leading techniques 3.adjustment of course contents
Teaching and Learning	Understanding and resolving barriers to student learning	1.case-based offline class 2.online Question and Answer 3.immediate feedback 4.open learning community
Laboratories and Workshops	Models for design and use of labs workshops	1.online practice and training (1)basis practice training (2)featured practice training 2.in-class experiments
Assessment	Tools and processes for teaching evaluation	1.statistic and assessment of platform 2.online anonymous evaluation 3.final exam 4.adjustment of evaluation

IV. Curriculum Structure Design Under CDIO Initiative

According to CDIO initiative, the software testing course should integrate the theoretical concepts with design-build experiences. It should emphasize practicality throughout the course to stimulate and strengthen the teaching of system establishment and broaden students' professional knowledge, so that students can clearly understand the strategic value of the software testing, which lay a solid foundation for them to become leading testing engineers and researchers in the future. Our software testing curriculum model consists of three parts: online course resources

libraries, lectures on leading techniques in industry and dynamic adjustment of course contents.

A. Online Course Resource Libraries

In order to equip students with the basic theoretical knowledge of software testing and facilitate their active and independent learning, an online course had been established on the EduCoder teaching and practice platform (its network location is https://www.educoder.net, the screenshot of our online class shown on Fig. 1). There is built an online course resource library where the syllabus, teaching videos, and teaching coursewares are uploaded for students to preview before class and review after class conveniently. Besides, the online teaching resources libraries also include the discussion theme library and unit test library. There are 16 carefully selected discussion themes in the discussion subject library, which are tightly related to the course, to help students deepen their understanding of the basic concepts and theoretical knowledge. And the unit tests are prepared according to the teaching schedule, so as to help students self check their loopholes and deficiencies in their learning and consolidate what they have learned.

B. Lectures on Leading Techniques in Industry

The CDIO education initiative advocates to integrate design-build experiences and practical techniques with existing courses teaching, so we invite the senior engineers in the industry of software testing to hold seminars on the leading testing technologies, practical experiences in testing, and the significance of software testing, etc.. These cutting-edge technology lectures cover different topics such as crowdsourcing software testing and artificial intelligence software testing, big data testing, blockchain testing and cloud testing, so that students can understand most leading testing technologies and development trends, while allowing students to recognize the importance of software testing and stimulate their interest in learning.

C. Adjustment of Teaching Content

We have adjusted the content of each chapter and the allocation of class hours according to the teaching content and teaching focus determined by a new understanding and analyzing the current development trend of software testing technology. Because the basic theory of software testing and the basic testing methods in white-box and black-box testing techniques have been taught in the “Introduction to Software Engineering” course, this part of the content would be assigned to students before class to learn independently through online teaching video materials and more practices could be done during class under teacher's guidance. In this way, more class hours are allocated to teach new and more advanced test theory and test analysis and design. Web functional testing and non-functionality testing such as performance testing, stress testing, security testing etc., are not introduced in other courses, and hence can be explained more in depth and comprehensively in class.

Our software testing course model is mainly based on offline teaching, with online teaching and lectures on leading techniques as assistance.

V. Teaching and Learning Improvement

CDIO framework requires improvement in teaching level to understand and help students to overcome obstacles in learning. Our design in this theme includes case-based offline teaching, online Q&A(question and answer), judge online and open learning community to facilitate students learning.

A. Case-based Offline Teaching

Since the course teaching model is mainly based on offline teaching, the use of case-based teaching methods in offline teaching can improve the teaching effect. According to the CDIO educational initiative, real-world systems or products should be selected in teaching, emphasizing the

Fig. 1 Screenshot of our online class of software testing

learning of practical technologies. Therefore, we choose open source projects of moderate size in offline classes, such as open source projects on GitHub, as teaching cases to analyze test requirements and design test cases. Through practical cases, students can learn the methods and theories of test design in application, so that they can clearly understand the importance of software testing technology and stimulate their interest in learning software testing technology. The use of specific open source projects as teaching cases, coupled with actual application scenarios, makes classes of test theory no longer abstract and obscure, so that students could better grasp the theoretical knowledge of testing.

B. Online Q&A

Timely feedback on the learning process according to the CDIO model can enhance learning performance. In the course of learning and practice, students will encounter many problems, then they could leave a message in DingTalk, Wechat or QQ groups for teachers and assistants to answer timely. We offer online Q&A in the DingTalk group.

C. Immediate Feedback

Immediate feedback could give learner the results of their learning timely, arouse their interests on learning. We adopt judge-online mechanism provided by the online teaching and practice platform, here is "Educoder" website, for online practice training and unit tests.

D. Open Learning Community

Setting up open learning communities, such as online forums, learning blog spare etc., is beneficial for learners in terms of enhancing learners' exchanges and discussions and providing support for the study of software testing courses.

VI. Laboratories and Workshops

In CDIO models, laboratory and workstation should develop experimental platforms to support course practice through including design and construction experience in experimental teaching and encouraging students to actively participate in team-based, hand-on projects. An experimental teaching plan can help make full use of the laboratory and experimental platform to improve the students' practical ability to test. On the basis of in-class experiment plan, we make full use of the existing network practice platform as an experimental one to carry out curriculum practice. On the premise of not increasing the experimental class hours, the students are intensively trained in testing. Our experimental plan consists of two parts, online training and in-class experiments.

A. Online Practice Training

On the basis of CDIO initiative, we take full advantage the current mature network teaching and training platforms to design and develop the course training. The online practice platforms we use include "EduCoder" platform and "MoocTest" platform (its network location is http://www.mooctest.net). EduCoder platform is a national, first-class curriculum construction practice platform, and the MoocTest platform is a platform dedicated to software testing, which has become an important platform to promote software testing professional construction and explore reform of practice teaching.

1) Basic practice training: We conduct basic training in the "practice training" section of the software testing teaching class of the Educoder platform (which we built and introduced earlier). In accordance with experiments syllabus, interesting practical training exercises were developed. The experimental content in the outline was designed as multiple practical test points, which were displayed in the form of games, and learners who successfully passed the test could obtain the corresponding gold coin value. There are currently 3 online practical training exercises for students, covering basic software testing techniques: white box testing, black box testing, and unit testing. The three online training exercises bear five tasks respectively practicing White box testing approaches: decision coverage, path coverage, and Black box testing approaches: equivalence partitioning, boundary value analysis, as well as Unit testing, Junit etc.. Online exercises can also provide timely feedback for students to iteratively make improvement according to the evaluation results and better master the fundamental testing approaches. They integrate game into testing training practice, which arise students interests in learning testing and promote their enthusiasm for learning.

gamification

2) Featured practice training: Taking advantage of specialized MoocTest platform, we develop the featured training to provide students with exercises such as mobile application testing, function testing and performance testing of Web applications, etc.. The greatest advantage of this platform is that it does not require complicated installation and configuration to complete all kinds of featured test training.

B. In-Class Experiments

In-class experiments refer to the experiments that occupy the course time and are arranged in college laboratory. There are eight hours for our in-class experiments, during which students will do basic testing experiments, such as statement coverage and path coverage in white-box testing approaches excluding exercises in the online practice training, cause-effect graph testing in black box testing approaches and automation testing, including the use of tools of UFT(Unified Functional Testing.

In general, online practice training is a useful supplement to in-class experiments, which can strengthen students' testing practice. This kind of training form, which is not limited in time and space, is more suitable for modern students, and is welcomed by them.

VII. Assessment

Teaching evaluation is a significant parts in CDIO model, which covers tools and process of assessment. In order to cooperate with the teaching reform of software testing course, we redesign the course assessment and evaluation mode. The evaluation mechanism consists of three parts: the statistics and evaluation of learning platform, final exam and adjustment of evaluation method.

A. Learning Platform Statistics and Evaluation Mechanism

The online course evaluates students' learning by statistic and assessment mechanism of the platform. To be specific,

online teaching video section can be evaluated by the recorded length of time that students spend watching videos in platform; discussion section can be assessed by times that students participate in online discussions; online practice training and unit tests can be automatically evaluated online, and online assignments could be assessed by anonymous evaluation among students.

B. Final Examination

The final examination is a common method used by colleges and universities to evaluate the students' learning outcomes, so we still use this method except that we put more emphasis on testing design in the examination.

C. Adjustment to Evaluation Mode

The original course assessment mostly grades students through final exam and class performance. This kind of assessment mode no longer suit online-offline blended teaching mode. In order to encourage student to actively learn online course resources like teaching videos, or videos of lectures on leading techniques, and participate in online discussions, and complete online practices, we adjust the ratios of each teaching sections to include online practical training exercises, online video viewing and discussion participation, the quality of assignments and experimental report into the grading of the whole course. In this way the proportion of the grade of the final exam is adjust to 60%, and online learning accounts for 40%. skill too much for exam

In a word, our CDIO-based online-offline hybrid teaching reform of software testing mainly consists of four parts. They are curriculum structure design, promotion in teaching and learning, experimental teaching in laboratory and workshop, and course assessment. It has been proved by trail that this teaching mode can improve students practical abilities, stimulate their interests in learning software testing, and make more progresses in class participation. The details will be shown in the next section.

VIII. Practices of Software Testing Course Reform

In the fall semester of 2020 , we tried CDIO-based online-offline blended teaching reform of software testing on some junior software engineering majors of School of Software in our university, who had completed related courses like "Introduction to software engineering", "Fundamentals of programming", etc. At the end of the course, we issued a questionnaire to 65 students, hoping to investigate the effect of the teaching reform. We mainly investigated whether the online resources of the course could help students learn the course better, and whether this teaching reform have any effect on improving students' abilities. Because the questionnaire was voluntary, eventually 54 students participated the survey. The questionnaire included five multiple choice questions, the statistic result of which is shown in Fig. 2. From the figure, we can see that there are respective 98%, 96% of students believe online teaching videos(Q1) and question discussion(Q2) are of great or more helpful for their course study, there are 94%, and 96%, 98% respectively think that online practice training of the course play a relatively or very significant role in improving their abilities in testing design(Q3), testing programming(Q4) and application programming(Q5). The number of participants in the questionnaire and the recognition of online course resources indicates that this teaching mode is popular among students, and CDIO-based online-offline hybrid software testing teaching reform is successful to some extent.

Besides the questionnaire, the average and the highest score of the final examination of 2018 grade is 65 and 89 points respectively, which are both 3-point higher than that of 2017 grade. Although there is only a 3-point improvement, it also verifies that our curriculum reform is successful to some extent.

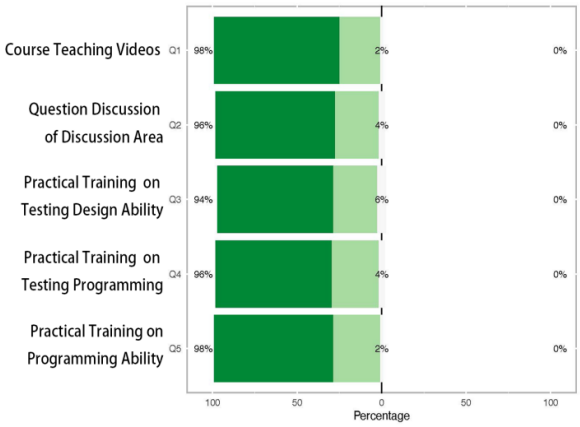

Fig.2. The importance of different online teaching resources and activities to course learning. Scale=strongly agree,agree, neutral, disagree, strongly disagree. The full questionnaire can be found in appendix[1].

IX. Conclusion

We apply CDIO engineering education initiative to the teaching reform of software testing in online-offline hybrid mode in college and universities. This reform takes advantage of online practice training in mature practice platform, which supplements in-class experiments, and reinforces the testing practice. Online course resources provide learning flexibility, and cultivate students' abilities of active learning; Case teaching based on open source projects provides undergraduate students with more realistic projects and usage scenarios. The reformed course teaching has been popular among students, which improves their testing skills and independent learning abilities.

Through the practice of teaching reform of this course, it is fully justified the guiding significance of the CDIO engineering education initiative in the reform of engineering education. At the same time, this practice also serves as a beneficial attempt and experiences for the reform of other engineering practice courses. In the future, we will continue to enhance online practice training to include more types of testing technology, security testing for instance, and develop some group works and practices to cultivate the cooperation spirits among students.

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APPENDIX

Table The statistic result of the full questionnaire

Qestion NO. 1	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
subtotal	40	13	1	0	0
proportion(%)	74.1%	24.1%	1.9%	0.0%	0.0%
number of valid questionnaires	54				

Qestion NO. 2	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
subtotal	38	14	2	0	0
proportion(%)	70.4%	25.9%	3.7%	0.0%	0.0%
number of valid questionnaires	54				

Qestion NO. 3	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
subtotal	37	14	3	0	0
proportion(%)	68.5%	25.9%	5.6%	0.0%	0.0%
number of valid questionnaires	54				

Qestion NO. 4	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
subtotal	37	15	2	0	0
proportion(%)	68.5%	27.8%	3.7%	0.0%	0.0%
number of valid questionnaires	54				

Qestion NO. 5	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
subtotal	38	15	1	0	0
proportion(%)	70.4%	27.8%	1.9%	0.0%	0.0%
number of valid questionnaires	54				