Evaluation method for CDIO project-based teaching, with total-process multi-assessment

Yarong Chen, Pei Li, Hongming Zhou & Peihong Fu

Wenzhou University
Wenzhou City, Zhejiang, People's Republic of China

ABSTRACT: As a solid foundation for the implementation of the *Excellent Engineers Plan* in China, CDIO (Conceive, Design, Implement, Operate) based engineering education has been widely promoted and practised in China. The traditional summative evaluation method is unable to meet the requirements of the CDIO project-based teaching. Hence, a new comprehensive evaluation method is presented in this article. This integrates summative with formative assessment, and involves multiple assessors, including the teacher, project team leader and team members. This method can stimulate the interest of students in team-based learning and improve teaching quality. The method was applied, as an example, to a course at Wenzhou University, Wenzhou City, Zhejiang, China.

INTRODUCTION

On 23 June 2010, a meeting concerning the *Excellent Engineer Education and Training Program* was held at Tianjin University by the Chinese Ministry of Education, together with relevant departments and industry associations, to implement the *Excellent Engineers Plan*. To date, nearly 350 colleges and universities with more than 1,500 specialties have implemented the *Excellent Engineers Plan* in China. Experience has shown that CDIO (Conceive, Design, Implement, Operate) project-based education is a good framework and foundation for excellent engineer training. Conceive, Design, Implement, Operate represents the direction that international engineering education is taking [1].

Compared with traditional teaching, CDIO places emphasis on practice and team co-operation [2]. The CDIO teaching is by project, and the conceiving, designing, implementing and operating of the resultant system are conducted through autonomous learning and co-operative inquiry by project team members. However, the traditional evaluation method is mainly outcome-oriented, evaluation is by the individual teacher and the evaluation is of the individual student. The final score is calculated as the weighted sum of attendance, mid-term examination and final examination. The examinations usually are closed. This traditional summative evaluation is not able to meet the requirements of CDIO project-based teaching, and, thus, it is necessary to study new evaluation methods.

CDIO PROJECT-BASED TEACHING AND APPROACHES TO EVALUATION

CDIO Project-based Teaching

Conceive, Design, Implement, Operate engineering education takes the life cycle of a system and product development as the driver of the curriculum. It integrates mutual support with organic connections between knowledge, so that students autonomously and practically acquire engineering knowledge and skills. The CDIO project curriculum covers the complete university teaching of the discipline [3].

For example, at Shantou University, the curriculum for the mechanical manufacturing and automation specialty is an integrated multi-level project system, which includes four first-level team projects, four second-level team projects, and one or several, third-level team projects for each course. During teaching, students form a collaborative team, select the system or product to develop, and undertake the project through autonomous learning and co-operative exploration of knowledge and problems, according to the process shown in Figure 1.

Figure 1 shows that the CDIO project involves complicated system engineering. Compared with traditional teaching, in CDIO project-based teaching, the students work in groups and learn a range of skills as they go through the whole

process of product and system conception, design, implementation and operation. The traditional summative evaluation method needs to be transformed into comprehensive formative and summative assessments. The evaluation should not only be by the teacher, but also include team leaders and team members. In addition, the object of the evaluation should be extended from the individual student's knowledge to include team co-operation, project participation and practical skills.

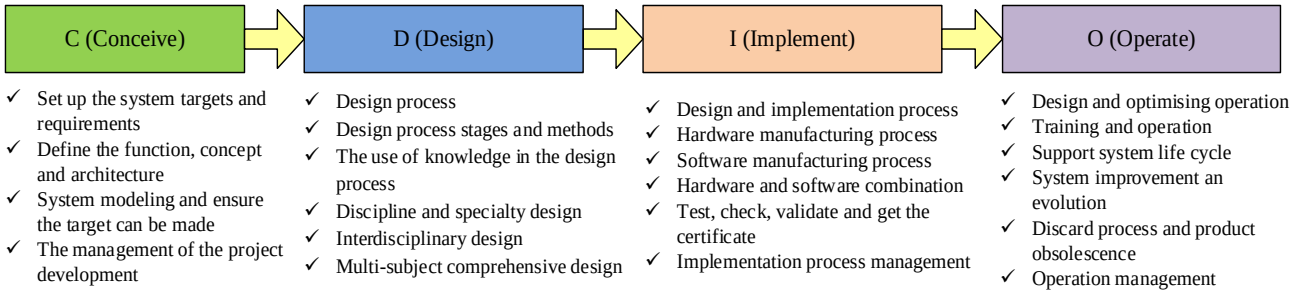

Figure 1: The CDIO project process.

Evaluation of CDIO Project-based Teaching

Traditional teaching evaluation methods include fuzzy comprehensive evaluation, the analytic hierarchy process (AHP), correlation matrix method, and so on. Taras pointed out that formative evaluation is much better at evaluating practice learning [4]. For the weight-consistency problem in AHP, Wang and Daiput put forward an order relation analysis method to determine the weight of each evaluation index, and a comprehensive evaluation model for a network course using fuzzy evaluation [5].

Liu and Zhang presented an integrated teaching evaluation method for a professional core course, which incorporates summative evaluation, formative evaluation and a traditional examination [6]. Wen pointed out that more attention should
be paid to process evaluation and multi-agent evaluation in the context of CDIO project-based teaching [3]. Zhang et al proposed a multi-assessment method for a university physics course suitable for peer teaching [7].

Based on the above literature search, a total-process, multi-assessment evaluation method for CDIO project-based teaching was selected to assure the effective implementation of the Excellent Engineers Plan.

TOTAL-PROCESS, MULTI-ASSESSMENT EVALUATION METHOD

The total-process, multi-assessment comprehensive evaluation method for project-based teaching has several characteristics:

- The assessment and evaluation cover the total process of project-based teaching, such as the team formation, the development of the implementation plan and the control of the project schedule. The performance evaluation of each team is mainly by the teacher and depends upon the project process and outcome.

- Multi-assessment includes the teacher and project team leader, as well as students' self-evaluation and students' mutual evaluation, so as to ascertain each team member's contribution. The evaluation of each team member is divided into two stages: the first is from an overall evaluation of the team, while the second is from the individual contribution of the student, as shown in Table 1. The final score of each member is comprehensively calculated by the weighted sum of overall evaluation and individual contribution evaluation.

Table 1: Total-process, multi-assessment of project teaching.

Object	Goal	Indicators	Methods
Whole team	Division of effort and co-operation on the project, practice, analysis and solution of problems by the team.	Project implementation planning, progress control, on-site data quality, depth of problem analysis, correct solutions chosen, rationality and validity of project results, understanding of logical connections among different projects, oral responses.	Final score S_{tm}* is ascertained on the basis of team *t*'s performance on project *m* by teachers.
Individual student	Perception, learning, and individual contribution to the project.	Ranking the team member contributions by teacher, group leader, other members, and self, to ascertain each member's contribution.	Order relation analysis* [5] to ascertain the contribution r_i of member i.

* See next section

Assessment Methodology

Assume the project is m (m = 1, 2, 3…, M), the team is t (t = 1, 2, 3…, T) and the members of t are t_k (k = 1, 2, 3…, K). The teacher assesses the overall score, S_{mt}, of team t on project m. The relative contribution of team member k is given by the teacher, team leader, member k him/herself and other members of the team using a simple ranking or pairwise comparison method. Members' relative contributions form the matrix W where w_{ij} is the assessment of the i^{th} assessor (students plus teacher) of the j^{th} student. The matrix $V = (v_1, v_2, \cdots, v_{k+1})$ are the different evaluation subject weights. The final individual contribution r_k of member k is calculated by Equation (1).

$$R = VW = \left(v_1, v_2, \cdots, v_{K+1}\right) \begin{vmatrix} w_{11} & w_{12} & \cdots & \cdots & w_{1k} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ w_{K+1,1} & w_{K+2,2} & \cdots & \cdots & w_{K+1,k} \end{vmatrix} \tag{1}$$

The final score of team member k is determined by the weighted sum of the overall and individual evaluation. If the average contribution of team members is mb; then, the score of member k of project m on team t is calculated by Equation (2).

$$S_{mtk} = S_{mt} \times (1 + mb - r_k) \tag{2}$$

Using a similar procedure, the score of member k on another project, say $m + 1$, also can be determined. The scores form a matrix S for all projects. The evaluation for member k can be calculated by considering the project's weight among other projects. Assuming the project weights matrix $M = (m_1, m_2, \cdots, m_M)$, the final score for the course can be calculated by Equation (3), where fs_k represents the final course score for team member k.

$$FS = SM = \begin{vmatrix} S_{11} & \cdots & S_{1M} \\ \cdots & \cdots & \cdots \\ S_{K1} & \cdots & S_{KM} \end{vmatrix} \left(m_1, m_2, \cdots, m_M\right) = (fs_1, fs_2, \cdots, fs_k, \cdots, fs_K) \tag{3}$$

The relative contribution of team member k generally is ascertained by a simple comparative ranking method as follows: the teacher, team leader and team members compare the relative contribution of each member in a group and sequence them accordingly. The greater than symbol is used to indicate that one is greater than another. The quantitative contribution of each team member can be determined by the simple method of assuming the ordinal ranking is the same as the quantitative value. Finally, the relative contribution of each member is determined by the ratio of individual to total contribution.

For example, assume a project team t has K (K = 4) members, respectively, t_1, t_2, t_3 and t_4. The teacher's ranking is $t_1 > t_3 > t_2 > t_4$, and so the contribution of t_1 is higher than t_3, and t_3 is higher than t_2, etc. According to this ordering, the contribution c_i of member t_i is given as, $c_1 = 1$, $c_3 = 2$, $c_2 = 3$, $c_4 = 4$. Since the total contributions add up to 10, the relative contribution of each member can be determined, $w_1 = 1/10 = 0.1$, $w_2 = 2/10 = 0.2$, and so on. Using the evaluation data from different evaluation subjects, allows the relative contribution matrix W of all members to be formed.

CASE STUDY

The College of Mechanical and Electrical Engineering at Wenzhou University has implemented CDIO project-based teaching since 2012. Two measures have been taken to avoid some possible problems with team-based learning, viz. team members *freeloading* by allowing other members of the team to do their work or the project process getting out of control.

The first problem is addressed by a team-leader rotation system in which each team member has to be a team leader once. By sharing responsibility in this way, co-operation, mutual learning and leadership are strengthened, and the gap between the students' project skills and enterprise engineering demand is reduced. The second problem is addressed by a process monitoring system in which each team must regularly publish their project progress against schedule on the course Internet.

The team should first plan the project, and regularly submit the actual project progress against the plan to the course Internet to ensure punctual completion. In addition, evaluation methods are constantly explored to improve teaching and learning quality. This is the reason for proposing the total-process and multi-assessment method.

The Fundamental Industry Engineering Course Example

The methods described in this article were applied to the fundamental industry engineering course. There are three types of project for the fundamental industry engineering course. Each project closely follows the CDIO project approach, i.e. project selection, planning, investigation, analysis, and so on. Each project is conducted in teams of 3-5 students. In the teaching, the overall evaluation score of each team on each project is determined by the teacher, according to the team's total-process performance. This includes the project plan, project report and project defence.

Assuming the score of team t on project m, S_mt, is equal to 85, and the members' number K of the team t is 5. The process to determine each member's score is as follows.

- The teacher, team leader and team members rank each member's contribution. The reason for distinguishing team leader and team members is to allow for different evaluation weights.

- The relative contributions are calculated by a simple comparative ranking. The data are shown in Table 2.

Table 2: Rankings to determine the relative contribution of each member.

Evaluator	Ranking	c_1	c_2	c_3	c_4	c_5	w_1	w_2	w_3	w_4	w_5
Teacher	$t_1>t_2>t_3>t_4>t_5$	1	2	3	4	5	0.07	0.13	0.20	0.27	0.33
Member 1 (leader)	$t_1>t_3>t_4>t_2>t_5$	1	4	2	3	5	0.07	0.27	0.13	0.20	0.33
Member 2	$t_1>t_3>t_2>t_4>t_5$	1	3	2	4	5	0.07	0.20	0.13	0.27	0.33
Member 3	$t_1>t_4>t_3>t_5>t_2$	1	5	3	2	4	0.07	0.33	0.20	0.13	0.27
Member 4	$t_1>t_3>t_2>t_4>t_5$	1	3	2	4	5	0.07	0.20	0.13	0.27	0.33
Member 5	$t_1>t_3>t_2>t_5>t_4$	1	3	2	5	4	0.07	0.20	0.13	0.33	0.27

- Assume the weight matrix for different evaluation subjects is V = (*0.3, 0.3, 0.1, 0.1, 0.1*). Each member's weight can be calculated by Equation (1), yielding R = (*0.07, 0.21, 0.16, 0.24, 0.32*).

  This means the contribution of member 1 is r_1 = 0.07, and so on.

- Averaging the weights of the team members gives the value of mb = 0.2. According to Equation (2), the set of scores for team t and project m can be calculated as S_m = (*96, 84, 88, 82, 75*), i.e. the score for member 1 is 96, the score for member 2 is 84, and so on. Using the different project weights allows the final course score to be determined.

This evaluation method can not only assess the learning achievements of each student fairly and objectively, but also encourages students to participate in team project-based learning.

CONCLUSIONS

With the near-universal implementation in China of the *Excellent Engineers Plan*, more engineering courses will be taught by project-based teaching. An effective evaluation of students' performance to give a fair score, directly influences the interest in learning and the quality of teaching. In this article, a comprehensive evaluation method was put forward, to remedy the disadvantages of the traditional evaluation method, which involves a single evaluation subject (teacher), evaluating an individual object (student). This new method is an integration of summative and formative assessment, and each student's performance is derived from the overall score of the whole team, together with scores derived from the opinions of the teacher, team leader and other team members. Therefore, it not only assesses the learning achievement of each student fairly and objectively, but also encourages students to participate in team learning, exploring with others and contributing to the completion of the project.

ACKNOWLEDGMENT

This work was supported by the Reform Programme of Higher Education in Zhejiang Province of China, (No.kg2013371).

REFERENCES

1. Gu, P., Lu, X., Xiong, G., Li, S. and Shen, M., The development of design directed engineering curriculum based on the CDIO framework. *World Trans. on Engng. and Technol. Educ.*, 5, **2**, 267-270 (2006).

2. Berggren, K-F., Brodeur, D., Crawley, E.F., Ingemarsson, I., Litant, W.T.G., Malmqvist, J. and Östlund, S., CDIO: an international initiative for reforming engineering education. *World Trans. on Engng. and Technol. Educ.*, 2, **1**, 49-52 (2003).
3. Wen, T., Exploration and construction of integrated Topcares-CDIO Talent developing mode. *China Higher Educ.*, 7, 41-43 (2011).
4. Taras, M., Assessment for Learning: Understanding Theory to Improve Practice. *J. of Further and Higher Educ.*, 31, **4**, 363-371 (2007).
5. Wang, J. and Dai Y., The fuzzy comprehensive evaluation model for network course on the basis of order relation analysis. *E-educ. Research*, 11, 55-58 (2009).
6. Liu, M. and Zhang, S., Exploration and practice of evaluation method for project integrated teaching. *China Market*, 44, 162-163 (2010).
7. Zhang, P., Tu, Q., Qi, W. and Ren, J., Multi-assessment model research on the basis of peer teaching-taking university physics for example. *China University Teaching*, 9, 60-62 (2013).