

# EXPLORATION AND PRACTICE OF THE CDIO ENGINEERING EDUCATION REFORM CONTROL SYSTEM

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## ABSTRACT

With the goal of cultivating talent, CDIO engineering education reform is a system engineering program that needs to be improved and perfected. Based on the analysis on the 12 CDIO Standards, a control system of CDIO Standards composed of three interrelated control systems, of which the innermost, middle and outermost layers are the control systems of courses, curriculum and cultivating mode respectively, is established by adopting the idea of control theory in this paper. Based on the CDIO life cycle analysis the three layers of courses, curriculum and cultivating mode, the keys for the CDIO standard control system to run efficiently are the three elements: education objectives, implementation methods and effect. Different realization matrices are defined in three levels by using the specific three elements of each level. Based on the realization matrices, the CDIO implementation control model is established, which puts forward the combination of qualitative and quantitative methods for CDIO engineering education reform system analysis and implementation. The method has been used in our college and has obtained a good result. Taking the ability standards as the cultivating standards, the second-level matrix method is used to integrate curriculum system and promote the teaching reform. The three-stage cooperation education of campus curriculum, university-enterprise cooperation curriculum, and enterprise practice is implemented to ensure the effective implementation of the program.

## KEYWORDS

CDIO, cultivating mode, realization matrix, curriculum system, control system, Standards: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12

With the goal of cultivating talent, CDIO engineering education reform is a system engineering program that needs to be improved and perfected. Adopting the idea of control theory, the CDIO engineering education reform can be designed and implemented effectively by establishing the control system of CDIO engineering education reform.

## 1. CONTROL SYSTEM OF CDIO STANDARDS

The 12 CDIO Standards are standardized forms of professional design and development guide for implementing CDIO. So it is of great importance to deeply understand the connotation of each standard and to clearly analyze the relationships between the 12 standards. Based on the analysis on the 12 CDIO Standards, it is found that Standard 1 (The Context) is determined by the education concept, missions, and professional goals of the

college; Standard 3 (Integrated Curriculum), Standard 4 (Introduction to Engineering) and Standard 5 (Design-Implement Experiences) specifies the standards of curriculum system; Standard 6 (Engineering Workspaces) provides the standards for the most important learning environment; Standard 7 (Integrated Curriculum), Standard 8 (Active Learning) and Standard 11 (Learning Assessment) specifies the standards of course teaching and learning; Standard 9 (Enhancement of Faculty Competence) and Standard 10 (Enhancement of Faculty Teaching Competence) specifies the standards for faculty development. Thus the 12 CDIO Standards could be categorized into seven modules, as shown in Table 1.

Table 1. Classification of CDIO Standards

Module	Standards
Module of the education concept, missions, and professional goals of the college	Standard 1 – The Context
Module of learning outcomes	Standard 2 – Learning Outcomes
Module of curriculum system (plan)	Standard 3 – Integrated Curriculum; Standard 4 – Introduction to Engineering; Standard 5 – Design-Implement Experiences
Module of learning environment	Standard 6 – Engineering Workspaces
Module of course teaching and learning	Standard 7 – Integrated Learning Experiences; Standard 8 – Active Learning; Standard 11 – Learning Assessment
Module of faculty development	Standard 9 – Enhancement of Faculty Competence; Standard 10 – Enhancement of Faculty Teaching Competence
Module of program evaluation	Standard 12 – Program Evaluation

Adopting the idea of control theory, a three-level control system of CDIO Standards can be established, as shown in Figure 1.

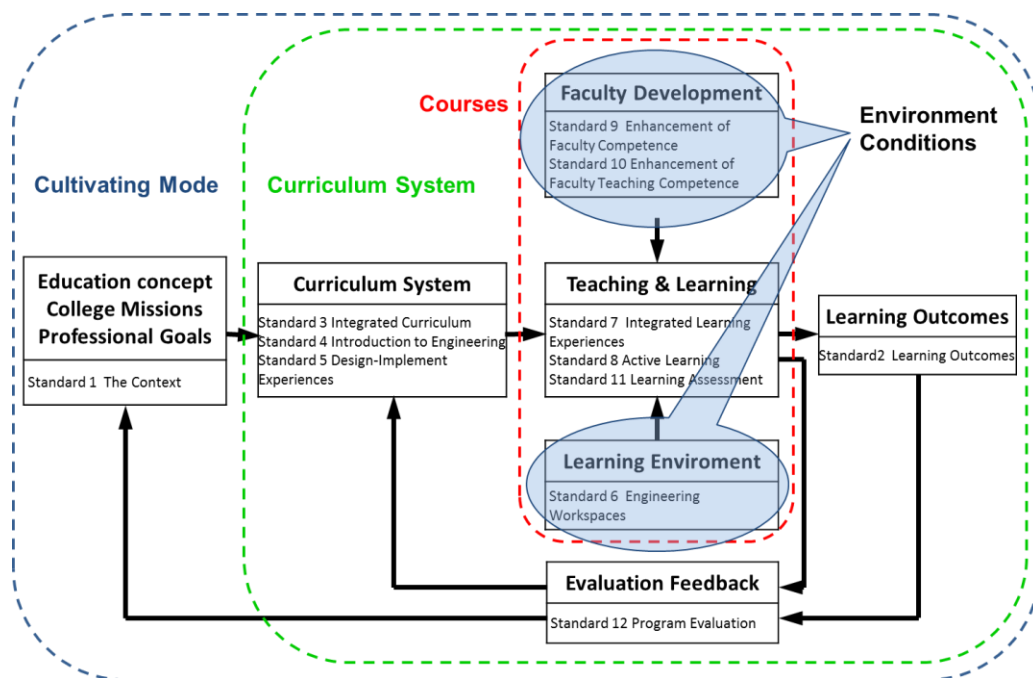


Figure 1. The control system of CDIO Standards

The control system of CDIO Standards consists of three interrelated control systems of courses, curriculum and cultivating mode. Course control system is the innermost layer, which consists of the modules of course teaching and learning and environmental conditions. The module of environmental conditions consists of two parts, which are faculty development and learning environment. Curriculum control system, which is the outer layer of the course control system, consists of the course control system, the modules of curriculum system, learning outcomes, and evaluative feedback. The outer layer of the curriculum control system is the cultivating mode control system, which consists of the curriculum control system and the modules of college orientation and evaluative feedback. The module of college orientation includes the educational concept, missions, and professional goals of the college, etc.

CDIO standards constitute a control system of engineering education reform, by which the connotation of each standard and the relationship between standards can be clearly and profoundly demonstrated. The control system of CDIO Standards mainly runs on three levels, each of which has its distinct undertaker, mission objectives, key points and standards. Course control system, whose main undertaker is teacher, centers around course teaching; curriculum control system, whose main undertaker is professor of specialty responsibility, centers around the specialty cultivating plan (curriculum); cultivating mode control system, whose main undertaker is dean or principle in charge of teaching of college, centers around the construction of cultivating mode. Based on the analysis of the control objectives, key points and operation situation according to the CDIO life cycle, a three-level CDIO operation mode can be formed, as shown in Figure 2. All three levels aim at the requirements of authentication department of government, student growth, industrial community and the development of science and technology and run according to the CDIO life cycle. Cultivating mode: conceive the cultivating mode according to the missions of the school, specialty cultivating goals and CDIO standards; then design cultivating plan and engineering workspaces; finally implement cultivating plan by the university-enterprise cooperative education and the construction of all kinds of engineering workspaces. The operation of cultivating mode is guaranteed by the construction of academic atmosphere, employment and program evaluation. Curriculum system: conceive the curriculum system according to the CDIO syllabus; then design a teaching plan; finally implement curriculum system by integrating curriculum and eminent faculty. The operation of curriculum system is guaranteed by teaching management and evaluation of curriculum system. Courses: conceive course teaching mode according to the CDIO syllabus and course teaching objectives; then design course outlines, project cases and course teaching instructions; finally implement course teaching reform by the reform of teaching methods, implementation of project cases and textbook compilation, etc. The operation of course teaching is guaranteed by the course evaluation, teaching inspection and course assessment, etc.

## **2. CDIO IMPLEMENTATION CONTROL MODEL**

The implementation of CDIO should be to refine the modules of standards, to determine the methods and procedure of implementation, to specify the operation rules and to explore the control strategy based on the control system of CDIO standards. Thus the CDIO implementation control model can be established.

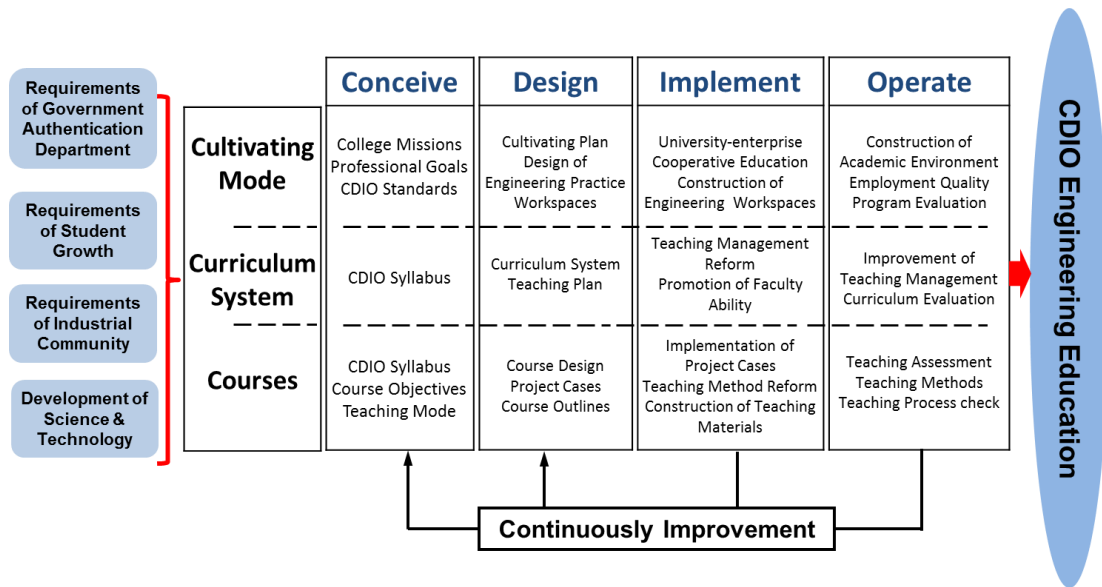


Figure 2. A three-level CDIO operation mode

### 2.1 Realization Matrix of Cultivating Standards

Based on the analysis of the three-level CDIO operation mode, cultivating objectives (standards), implementation approaches and implementation effects are the three key elements for the control system of CDIO standards to run effectively. Hence in each level the three elements should be clarified and refined. The three elements constitute the practice space of engineering educational reform, as shown in Figure 3. Taking the cultivating standards as one coordinate and implementation approaches as another coordinate, the two coordinates constitute a two-dimensional space, which is the design space of cultivating plan. Then taking the implementation effects as the third coordinate, a three-dimensional space, which is the practice space of education and teaching reform, is constituted. In this space, realization matrixes of cultivating standards are defined. In the realization matrixes, columns represent cultivating standards, rows represent implementation approaches, the values of matrixes represent the implementation effect of adopting the designed implementation approach for a certain cultivating standard, which is evaluated on a five-point scale, as shown in Figure 4.

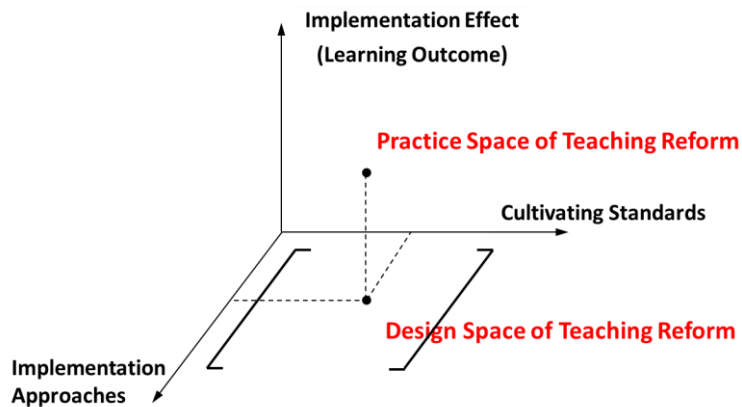


Figure 3. The practice space of education and teaching reform

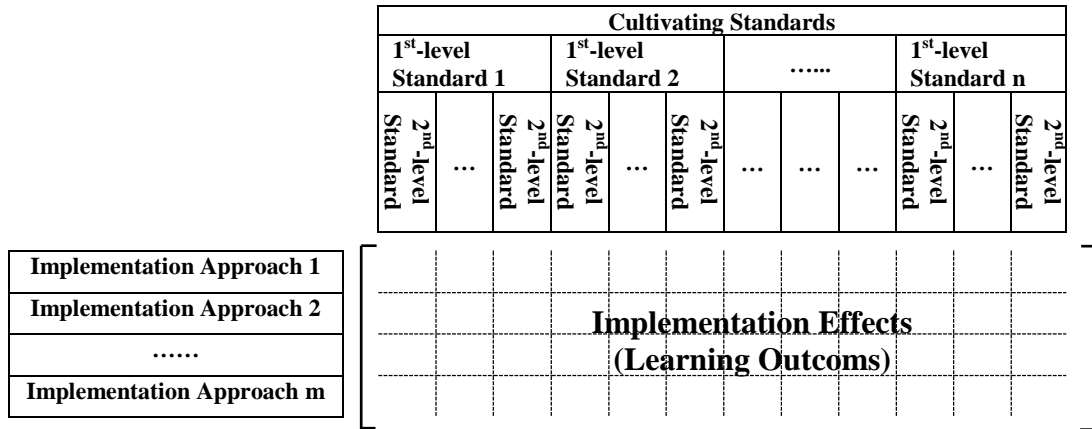


Figure 4. The realization matrix of cultivating standards

The corresponding first-level cultivating standards can be implemented by curriculum modules and courses. Thus, the first-level realization matrix is defined, as shown in Figure 5. The first-level realization matrix clearly demonstrate what kinds of curriculum systems are required to realize the specialty cultivating standards and which course modules and courses are required to realize a certain first-level cultivating standard simultaneously, as well as their implementation effects. It puts forward specific requirements and goals for each course of the cultivating plan. The first-level realization matrixes can be used to describe different kinds of education and teaching reform practice, such as the design, integration and evaluation of curriculum system, etc.

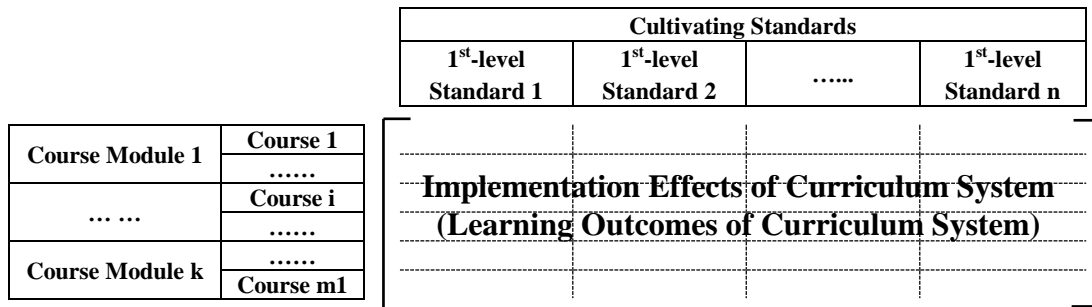


Figure 5. The first-level realization matrix of cultivating standards

The corresponding second-level cultivating standards can be implemented by course teaching programs and methods. Thus the second-level realization matrix is defined, as shown in Figure 6. Course teaching process is generally composed of the three segments of theoretical teaching, practice teaching and assessment. Theoretical teaching methods include classroom lectures, laboratory lectures, seminars, project learning, self-culture, and so on. Practice teaching methods include individual operation, group operation, industrial implementation, project practice, independent practice and so on. Assessment methods include written test, operation, paper, defense, test of openness, and so on. Second-level realization matrixes clearly demonstrate which teaching segments and methods are required to realize the course cultivating objectives, and the teaching effects. It can be used by course director and teachers to formulate the course outlines, to write lecture notes or teaching materials, to design course teaching plan, to implement course teaching and to evaluate course teaching effects accordingly. The second-level matrixes can be used to describe

different kinds of education and teaching reform practice, such as the design, integration and evaluation of course teaching, etc.

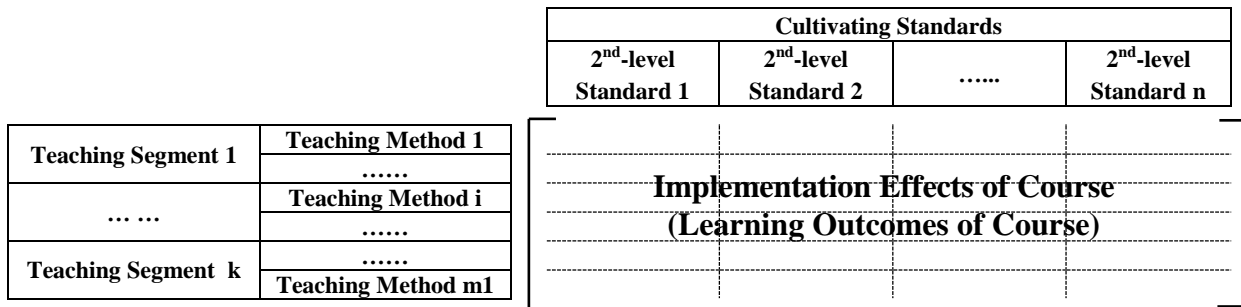


Figure 6. The second-level realization matrix of cultivating standards

## 2.2 CDIO Implementation Control Model Base on Realization Matrix

### 2.2.1 The Structure of CDIO Implementation Control Model

The realization matrix of cultivating standards defines the expression form of three elements in three levels. Defining it as the form of basic variables, and adopting the method of system engineering and control theory, in the education teaching reform practice space, the implementation control model of CDIO standard control system is established, as shown in figure 7. Based on the realization matrixes, the three-level CDIO implementation control model reveals the basic laws of the teaching reform practice, refines the CDIO standard control system, and puts forward the combination of qualitative and quantitative methods for CDIO engineering education reform system analysis and implementation.

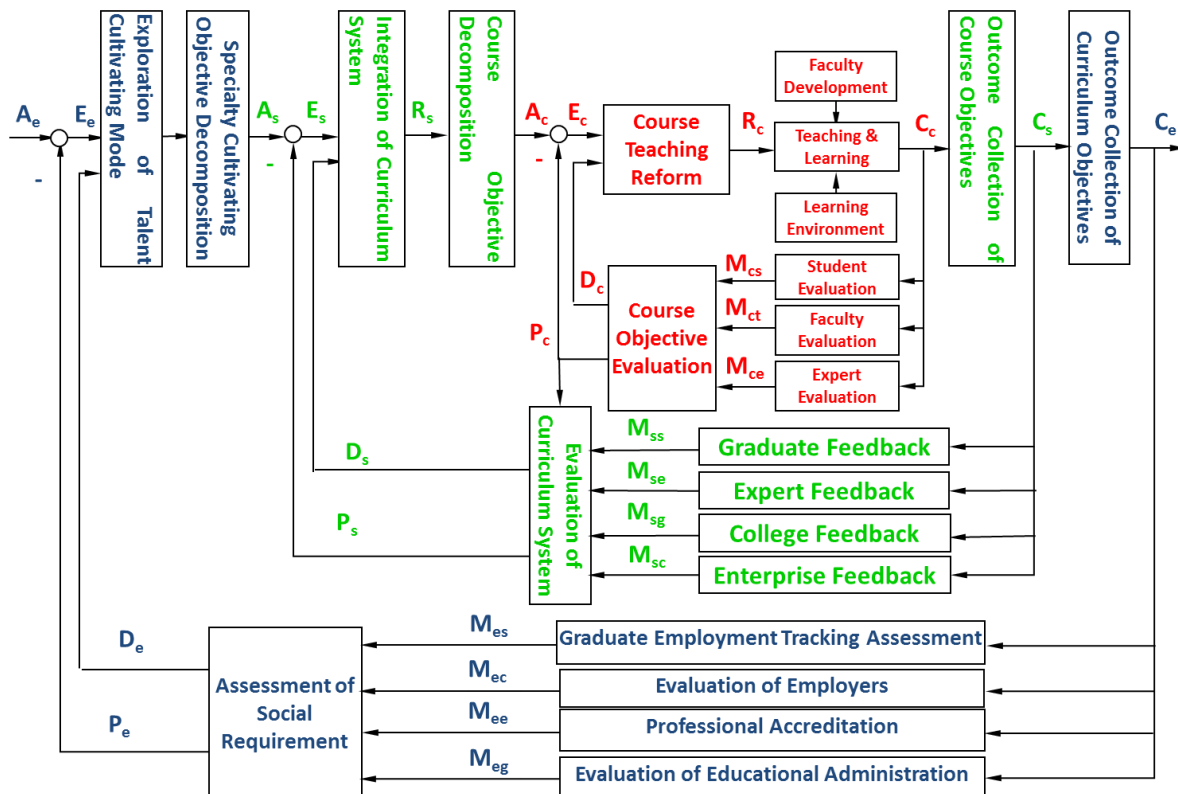


Figure 7. The CDIO control model based on realization matrix

Variable declaration:

$m$ ---number of specialty cultivating objectives;  $m_1$ ---number of curriculum system objectives;  $n_1$ ---number of courses;  $m_2$ ---number of course objectives;  $n_2$ ---number of teaching methods.

$A_e$ ---target matrix of specialty cultivating objectives ( $1 \times m$ );  $C_e$ ---output matrix of specialty cultivating objectives ( $1 \times m$ );  $P_e$ ---evaluation matrix of specialty cultivating objectives ( $1 \times m$ );  $E_e$ ---deviation matrix of specialty cultivating objectives ( $1 \times m$ );  $D_e$ ---evaluation difference matrix of specialty cultivating objectives ( $1 \times m$ ).

$A_s$ ---target matrix of curriculum system objectives ( $1 \times m_1$ );  $R_s$ ---realization matrix of curriculum system objectives ( $n_1 \times m_1$ ) (i.e. first-level realization matrix of cultivating standards);  $C_s$ ---outcome matrix of curriculum system objectives ( $n_1 \times m_1$ );  $P_s$ ---evaluation matrix of curriculum system objectives ( $1 \times m_1$ );  $E_s$ ---deviation matrix of curriculum system objectives ( $1 \times m_1$ );  $D_s$ ---evaluation difference matrix of curriculum system objectives ( $n_1 \times m_1$ ).  $A_c$ ---target matrix of course objectives ( $1 \times m_2$ );  $R_c$ ---realization matrix of course objectives ( $n_2 \times m_2$ ) (i.e. second-level realization matrix of cultivating standards);  $C_c$ ---outcome matrix of course objectives ( $n_2 \times m_2$ );  $P_c$ ---evaluation matrix of course objectives ( $1 \times m_2$ );  $E_c$ ---deviation matrix of course objectives ( $1 \times m_2$ );  $D_c$ ---evaluation difference matrix of course objectives ( $n_2 \times m_2$ ).

The model consists of a main line, three control loops and seventeen realization matrixes of six categories. The main line is that of cultivating objectives, which decomposes the specialty cultivating objectives into curriculum system, courses and teaching methods, for which distinct realization matrixes of cultivating objectives are structured respectively. The main line alternates among cultivating objectives, deviation and realization matrixes. The three control loops are the control loops of specialty cultivating mode reform, curriculum system reform and course teaching reform. The control loops are used to implement education and teaching reform on three levels, which are of specialty cultivating mode, curriculum system and courses. Driven by the feedbacks of quantitative evaluation, teaching reforms become objective explicit, enforceable, evaluable and controllable. The six categories of realization matrixes includes: target matrixes A, realization matrixes R, outcome matrixes C, evaluation matrixes P, deviation matrixes E, and evaluation difference matrixes D. On these matrixes, defined on the basis of the basic form of the realization matrix of cultivating standards, the operations of decomposition, set and statistic calculations can be taken.

### *2.2.2 The Control Loop Analysis of CDIO Implementation Control Model*

#### (1) The control loop of specialty cultivating mode reform

The cultivating objectives, the realization matrixes and the feedbacks of social requirement evaluations constitute a control loop of specialty cultivating mode reform, as shown in Figure 8. This is an open loop for exploring talent cultivating mode with two functions, which are formulating specialty cultivating objectives and standards and driving the whole control system to realize the target of specialty cultivating objectives on the basis of the deviations of cultivating standards and social command evaluations.

In a control loop, according to the orientation of the orientations of school, specialty, social requirements, education resource conditions, and so on, the specialty cultivating objective matrix  $A_e$  is determined, the cultivating mode is explored and the matrix of curriculum system cultivating objectives (standard)  $A_s$  is formulated. Diversified social requirement evaluations are taken from employment tracking of graduates (graduate databases), evaluations of

employers (e.g. enterprises), professional accreditation, assessment of education management departments, etc. The outcome matrix  $C_e$  is measured (evaluated) by the evaluation matrix of cultivating objectives  $P_e$ . The deviation matrix  $E_e$  and the evaluation difference matrix of plural society commands  $D_e$  are used to adjust the talent cultivating mode and curriculum system cultivating standards, and to promote the specialty cultivating mode reform.

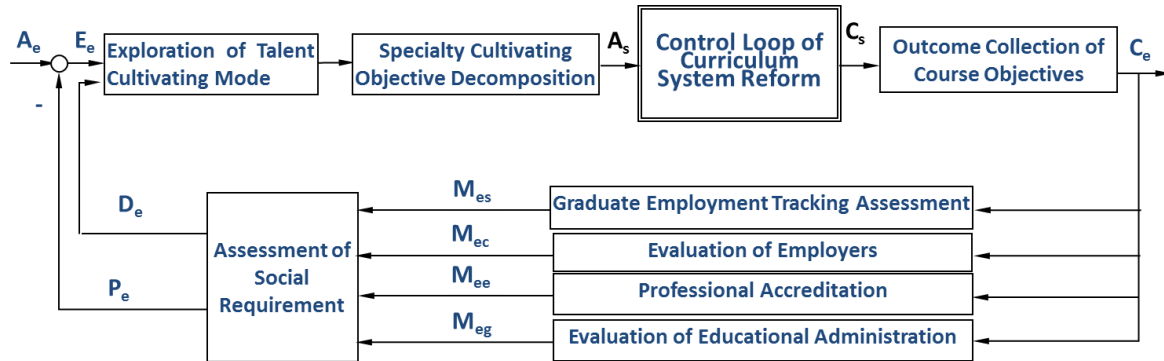


Figure 8. The control loop of specialty cultivating mode reform

Suppose the weight coefficients of the multi-evaluation of specialty cultivation are  $\alpha_1, \alpha_2, \alpha_3, \alpha_4$ .

The evaluation matrix of specialty cultivating objectives is  $P_e = \frac{1}{4} [\alpha_1 M_{es} + \alpha_2 M_{ec} + \alpha_3 M_{ee} + \alpha_4 M_{eg}]$ .

The evaluation difference matrixes of specialty cultivating objectives are  $D_{e1} = M_{es} - M_{ec}$ ,  $D_{e2} = M_{es} - M_{ee}$ ,  $D_{e3} = M_{es} - M_{eg}$ ,  $D_{e4} = M_{ec} - M_{ee}$ ,  $D_{e5} = M_{ec} - M_{eg}$ ,  $D_{e6} = M_{ee} - M_{eg}$ .

The deviation matrix of specialty cultivating objectives is  $E_e = A_e - P_e$ .

## (2) The control loop of curriculum system reform

The specialty cultivating objectives, the main line of first-level realization matrixes and the feedbacks of curriculum system evaluations constitute a control loop of curriculum system reform, whose model is shown in Figure 8. The loop has three functions. One is to formulate the first-level realization matrixes of cultivating standards, to integrate the curriculum system and make the specialty cultivating plan; the second is to decompose and determine course training objectives (standards) and drive course teaching reform; the third is to evaluate the first-level realization matrixes and continuously reinforce the reform of curriculum system by means of feedback control.

The control loop explores curriculum structure, courses, teaching contents, and so on; formulate first-level realization matrix  $R_s$ ; integrate curriculum system; make specialty cultivating plan; decompose and formulate course training objectives (standards)  $A_c$ , and drive the course teaching reform based on the curriculum system cultivating objectives (standards)  $A_s$  determined by the control loop of specialty cultivating mode reform. The collection of course training objectives  $C_c$  constitute the output matrix of curriculum system objectives  $C_s$ . Based on the outcome of curriculum system objectives measured by the multiple evaluation method of graduates, experts, college and cooperative enterprises and the collection of course objective evaluations, the evaluation matrix of curriculum system objectives  $P_s$  is derived. Then the first-level realization matrix  $R_s$  can be adjusted according to the deviation matrix  $E_s$  and multi-evaluation difference matrix  $D_s$ , which leads to the further



integrations of curriculum system and adjustments of specialty cultivating plan. Thus the teaching reform of curriculum system is promoted.

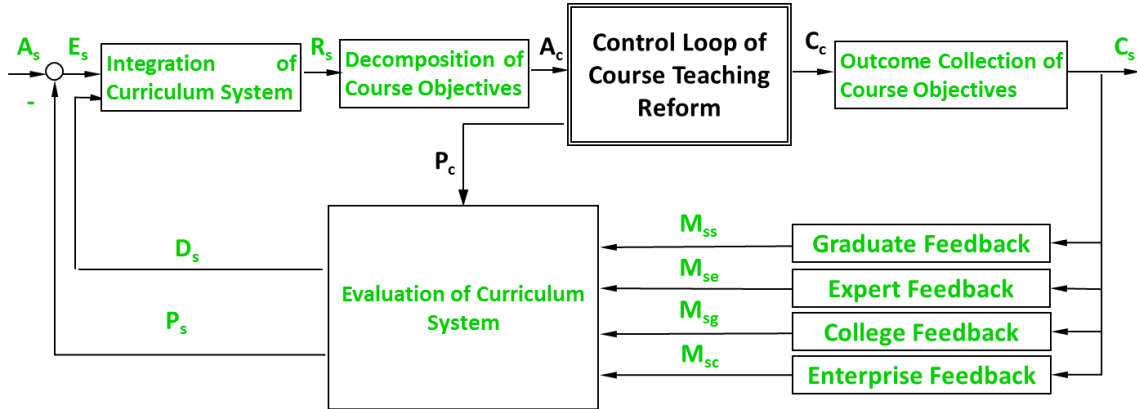


Figure 9. The control loop of curriculum system reform

Suppose the weight coefficients of multi-evaluation of curriculum system are  $\beta_1, \beta_2, \beta_3, \beta_4$ . The measurement matrix of curriculum system objectives is  $M_{sr} = \frac{1}{4}[\beta_1 M_{ss} + \beta_2 M_{se} + \beta_3 M_{sg} + \beta_4 M_{sc}]$ .

The matrix of the collections of course objective evaluation is  $M_{sc} = [1 \ 0 \ \dots \ 0]_{1 \times n1}^T \cdot P_{c1} + [0 \ 1 \ 0 \ \dots \ 0]_{1 \times n1}^T \cdot P_{c2} + \dots + [0 \ 0 \ \dots \ 0 \ 1]_{1 \times n1}^T \cdot P_{cn1}$ , where  $P_{ci}$  is the objective evaluation matrix of the  $i^{\text{th}}$  course.

All categories of evaluation matrixes are integrated according to their different weights of  $\beta_5, \beta_6$ , as  $M_s = [1 \ 1 \ \dots \ 1]_{1 \times m1} [\beta_5 M_{sr} + \beta_6 M_{sc}]$ .

The evaluation matrix of curriculum system objectives is  $P_s = \left[ \frac{M_s(1)}{b_1}, \frac{M_s(2)}{b_2}, \dots, \frac{M_s(m1)}{b_{m1}} \right]$ , where  $b_i$  is the number of nonzero elements in the  $i^{\text{th}}$  column of  $[\beta_5 M_{sr} + \beta_6 M_{sc}]$ .

The evaluation difference matrixes of curriculum system objectives are  $D_{s1} = M_{ss} - M_{se}$ ,  $D_{s2} = M_{ss} - M_{sg}$ ,  $D_{s3} = M_{ss} - M_{sc}$ ,  $D_{s4} = M_{se} - M_{sg}$ ,  $D_{s5} = M_{se} - M_{sc}$ , and  $D_{s6} = M_{sg} - M_{sc}$ . The deviation matrix of specialty cultivating objectives is  $E_s = A_s - P_s$ .

### (3) The control loop of course teaching reform

The course teaching goals, the main line of second-level realization matrixes and the feedbacks of course teaching evaluations constitute the control loop of course teaching reform, whose model is shown in Figure 10. The loop has three functions. One is to build the second-level realization matrix of cultivating standards and to implement course teaching reform. The other is to evaluate the second-level matrix and to continuously deepen the course teaching reform by means of feedback control.

The control loop explores the course teaching reform of teaching contents, teaching programs, teaching methods and teaching means, structure the second-level realization matrix  $R_c$ , make course teaching outline, and implement course teaching reform according to the course teaching goals (standards)  $A_c$  determined by the control loop of curriculum system reform. Based on the output of course teaching objectives measured by the multi-evaluation methods of students, teachers and experts, the evaluation matrix of course objectives  $P_c$  is derived. Then the second-level realization matrix  $R_c$  can be adjusted according to the deviation matrix  $E_c$  and multi-evaluation difference matrix  $D_c$ , which leads to the adjustments

of course teaching outline and the further adjustments of course teaching. Thus the course teaching reform is promoted.

The control loop is the most basic control in the whole engineering education reform control system, and the heaviest and most concrete control as well. It is the key of the implementation of the whole control system. Its control cycle is the shortest of the three control loop. Therefore, it has the fastest response. The effect collection, in turn, powerfully promotes the reform of the curriculum system and the talent cultivating mode.

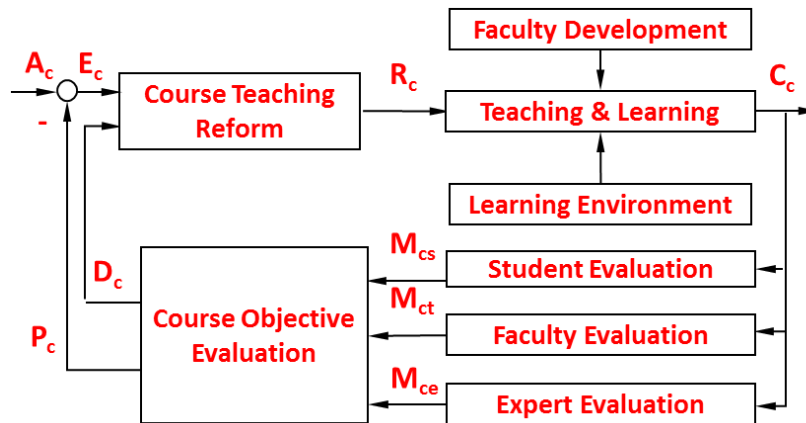


Figure 10. The control loop of course teaching reform

Suppose the weight coefficients of multi-evaluation of course teaching are  $\gamma_1, \gamma_2, \gamma_3$ . The measurement matrix of course teaching objectives is  $M_c = [1 \ 1 \ \dots \ 1]_{1 \times m_2} \cdot M_{cr}$ , where  $M_{cr} = \frac{1}{3}[\gamma_1 M_{cs} + \gamma_2 M_{ct} + \gamma_3 M_{ce}]$ .

The evaluation matrix of course teaching objectives is  $P_c = \left[ \frac{M_c(1)}{b_1}, \frac{M_c(2)}{b_2}, \dots, \frac{M_c(m_2)}{b_{m_2}} \right]$ ,

where  $b_i$  is the number of nonzero elements in the  $i^{\text{th}}$  column of  $M_{cr}$ .

The evaluation difference matrixes of course teaching objectives are  $D_{c1} = M_{cs} - M_{ct}$ ,  $D_{c2} = M_{cs} - M_{ce}$ , and  $D_{c3} = M_{ct} - M_{ce}$ .

The deviation matrix of course teaching objectives is  $E_c = A_c - P_c$ .

### 2.2.3 Teaching Reform Analysis of CDIO Implementation Control Model

Based on the analyses of control system above, it can be found that realization matrix R is top-level designed by educators, the evaluation matrix P is the measurement of objective output. Deep analysis on the matrix P can effectively improve the design of realization matrix R. Thus the objective output expected can be reached.

#### (1) Analysis of contribution degrees of implementation approaches

In realization matrixes, contribution degree and the effectiveness of realization mode for cultivating standard is the most important index. According to the analysis of evaluation matrixes, definition of contribution factor  $f$  and contribution ratio  $v$  is used to describe the contribution degree of realization mode for goal output. Analysis of contribution degrees is one of the most important method to optimize realization matrixes and to implement cultivating standards.

Assuming the weighting matrixes is  $Q$  ( $1 \times m$ ), the goal evaluation matrixes is  $P$  ( $1 \times m$ ), and the goal measurement matrixes is  $M$  ( $n \times m$ ), so the contribution factor  $f = P \cdot Q^T$ , contribution ratio  $v = M \cdot Q^T$

For curriculum system, assuming goal weighting matrixes is  $Q_s$ , the contribution factor of curriculum is  $f_{si} = P_{si} \cdot Q_s^T$ . The larger  $f_{si}$  is, the higher the degree of implementation of cultivating objectives based on the curriculum system designed is.

The contribution ratio matrix of courses is ( $V_s = M_{sr} \cdot Q_s^T$ ). By normalization,  $V_s = V_s / \sum_{i=1}^{n_1} V_s(i)$ . Under the scale of normalization, based on measurement matrixes curriculum system objectives, the contribution ratios of all courses for cultivating objectives can be quantitatively evaluated, the distribution of courses contribution ratio can be analyzed. Thus the courses with low contribution ratio are eliminated and integrated, the courses with high contribution ratio are strengthened and the courses with close contribution ratio are concentrated to form new courses. Finally the development of modularity courses can be strengthened and the effectiveness and pertinence of curriculum system reform can be improved.

For curriculum, assuming goal weighting matrix of course is  $Q_c$ , contribution factors of courses are  $f_{ci} = P_{ci} \cdot Q_c^T$ . The larger  $f_{ci}$  is, the more contributions are made by the courses designed to the cultivating objectives.

The contribution matrix of teaching methods is ( $V_c = M_{cr} \cdot Q_c^T$ ). By normalization,  $V_c = V_c / \sum_{i=1}^{n_2} V_c(i)$ . Under the scale of normalization, based on the outcome measurement matrix of course objectives goal output of courses, the contribution ratio of all teaching methods for cultivating objectives can be quantitatively evaluate, the distribution of contribution ratio of teaching methods can be analyzed. Thus the teaching methods with low contribution ratio are eliminated and adjusted, the teaching methods with high contribution ratio are strengthened, and the teaching methods with close contribution ratio are concentrated to innovate and exploit new teaching methods. Finally, the effectiveness and pertinence of course teaching reform are improved.

## (2) Weight analysis of cultivating standards

The professional cultivating standards consist of a series of indices with different weight, which can be divided into setting weight and evaluating weight. Setting weight is set by educator based on one's own educational ideas, cultivating goals and the understanding of goal and index system, corresponding related index. Besides, the educated also has his own understanding of goal, index system and weight. According to the measurement of learning outcomes, we can get the evaluation of setting index system and setting weight from educated which can be called evaluating weight. When the setting weight is consistent with the evaluating weight, the education reached the best situation, if not, we need to reform education system, integrate courses system, improve curriculum teaching system and even to adjust the index system and the setting weight.

The evaluation weight matrixes of curriculum system and course objectives are set weight. The evaluation weight can be derived by objective measurement matrixes.

The evaluation weight matrix of curriculum system objectives is  $Q_{sp} = M_{sr} / \sum_{j=1}^{m_1} M_{sr}(j)$ .

The evaluation weight matrix of course objectives is  $Q_{cp} = \frac{M_{cr}}{\sum_{j=1}^{m2} M_{cr}(j)}$ .

Under the normalization, according to calculate evaluating weight matrixes, the differences between set weight with evaluation weight can be compared. Studying the rationality and scientificity of goal setting, goal decomposition and index system, discuss the difference of top design and practice of teaching reform, adjust the index with low weight, analyze the index with excessive high weight, set the weight reasonably, balance the weight of index, leading teaching design and teaching arrangement to a status of scientific and reasonable.

### (3) Correlation analysis of cultivating standards and the implementation approaches

Actually,  $M_{cr}$  (goal measurement matrixes of courses) and  $M_{cs}, M_{ct}, M_{ce}$  (evaluation matrixes of courses) are evaluation interrelated matrixes of curriculum goal and teaching methods. In actual operation process, uncertainty is exist because of difference of evaluation subjects, environments and conditions, so evaluation uncertainty probability is introduced to optimize the options of teaching methods by correlated analysis of interrelated matrixes using statistical methods and to optimize the settings of teaching links by clustering analysis.

In a similar way, measurement matrix of curriculum system objectives  $M_{sr}$ , evaluation collection matrix of course objectives  $M_{sc}$  and evaluation matrix of curriculum system  $M_{ss}, M_{se}, M_{sg}, M_{sc}$  are evaluation interrelated matrixes of curriculum system goal and courses. we can optimize the settings of courses and courses model and strengthen the integration and construction of courses by correlated analysis of these matrixes.

### (4) Difference analysis of evaluation matrixes

#### ① Difference analysis of course teaching evaluation

Because of the diversification of evaluation subject,  $M_{cs}, M_{ct}, M_{ce}$  (evaluation matrixes of courses) definitely have differences, evaluation from students maybe a little pessimistic ,evaluation from teachers maybe a little optimistic and from experts maybe much more objective while not deep going. One goal of teaching reform is decrease the difference of evaluation matrixes by continuous adjusting, curriculum construction reached a relative excellent status while the difference kept in a low level.

In order to decrease the difference, First, we need to make clear how big the difference is and the relationship of the two sides. For integrity difference or factors with big difference, Taking effective methods during teaching reform process and decreasing differences gradually, based on making clear the difference of related sides, are good measures to strengthen curriculum construction.

Integrity difference could be expressed by calculating the distance of two matrixes which defined as Norm F of matrixes difference. For example, distance of evaluation matrix of teachers  $M_{ct}$  and evaluation matrix of students  $M_{cs}$  is defined as:

$$d(M_{ct}|M_{cs}) = \|M_{ct} - M_{cs}\| = \|D_{cts}\| = \left( \text{tr}(D_{cts}^T \cdot D_{cts}) \right)^{\frac{1}{2}} = \left( \sum_{i=1}^{n2} \sum_{j=1}^{m2} D_{cts}^2(i, j) \right)^{\frac{1}{2}}$$

According to calculate the distance of different evaluation matrixes, we can analyze the integrity difference of different subject, study the relationship of different subject, such as, if there is fixed deviation, the relationship between deviation and subject's standpoint and operation, the relationship between teacher's fixed deviation and his education theory and

ethics, the relationship between student's fixed deviation and his attitude, method and growing process, the relationship between expert's fixed deviation and his evaluation method and education theory etc. During the way to integrate courses, to design curriculum outline and to implement courses teaching, these analyses could help us to avoid deviation, especially those big, fixed ones, and to push curriculum teaching reform with pertinence and effectiveness.

The difference of evaluation factors can be expressed by  $D_{cts}$ ,  $D_{cte}$ ,  $D_{ces}$  directly. According to analyze the difference between evaluation factors, we can analyze the difference between different subjects during the way to evaluate a certain teaching method. Promoting the reform of a certain teaching method with clear goal, especially the factors with big difference, is the key point and difficult point of curriculum teaching reform, and the goal of the reform is to decrease the difference.

## ② Difference analysis of curriculum system evaluation

As the same as the analysis above, the constituent part of subject, besides the graduate, expert, college and enterprise, has  $M_{sc}$  added, which is the evaluation of control loop of curriculum teaching reform. The evaluation is synthesized by courses goal evaluation, it's a indirect evaluation to curriculum system, but it is the most practical because it's based on concrete teaching methods and courses goal evaluation, so  $M_{sc}$  is relative objective. Therefore, during the difference analysis of curriculum system evaluation, both subjective and objective factors can be introduced and group decision theory and cluster analysis can be used to deeply analyze the difference between the entirety and the section (related courses) of the curriculum system, and to effectively promote the integration of curriculum system and the education reform of courses model and courses arrangement.

## 3. TEACHING REFORM PRACTICE BASED ON CDIO ENGINEERING EDUCATION REFORM CONTROL MODEL

The CDIO engineering education reform control system is used in our college. Taking the ability standards as the cultivating standards, the two-level matrix method is used to integrate curriculum system and promote the teaching reform. The three-stage cooperation education of campus curriculum, university-enterprise cooperation curriculum, and enterprise practice is implemented.

The cultivating goal of Automation can be divided into three kinds: type, specialty and capability, based on orientation of the college and major, requirement of society, education sources, the goal of type can be defined as practical backup engineer, based on the analysis of professional orientation, industry development and the employment survey of graduate, the goal of specialty can be defined as system engineer, and the target matrix of specialty cultivating objectives is  $A_e = [\text{practical, automation system engineer}]$ .

Based on the control loop of specialty cultivating mode reform and analysis on the social requirement, the cultivating mode is explored and the competence cultivating objectives of curriculum system are determined. Goal of capability can be divided into two kinds: general engineering capability and specialty capability. Based on the synthesized analysis of the type goal, specialty goal, human resources requirement of various enterprises, employment development of the graduate, specialty standard from Steering Committee of Education ministry, policy from education management department of all levels, CDIO syllabus and

professional certification standard of ABET engineering specialty, ten general engineering capability indices are defined. Based on investigation of the graduate, specialty analysis, industry analysis, analysis of various professional people's growth, seven capability goals of automation specialty are defined. These 17 capability goals, related to cultivating goals of curriculum system, are the cultivating standards under capability-oriented cultivating mode.  $A_s$ -cultivating goals matrixes of curriculum system-can be expressed as follows:

$A_s$ =[project reasoning ability(recognizing, modeling, resolving), ability of resolving engineering problem synthesizing technology, technique and modern tools, ability of experiment and searching knowledge, systemic thinking ability, thinking ability with innovation and criticism, correct recognition of professional moral, ethics and responsibility, learning ability and correct recognition of lifelong learning, ability of team-based organization, cooperation and fusion, interpersonal communicating and expressing ability, correct recognition of modern issues and how engineering problem affect global economy, environment, society, application ability of mathematics, natural science and engineering, integrated designing ability of electronic system, computer programming ability of engineering control, analyzing and designing ability and digital simulation ability of automatic control system, designing ability and production integrating ability of automatic control system, installing, debugging and maintaining ability of automatic, practicing ability in enterprise].

To construct engineering competence objective cultivating oriented curriculum system, the control system of curriculum system reform based on first-level matrix can be used. The first-level realization matrix  $R_s$  is constructed by the target matrix of curriculum cultivating objectives  $A_s$ , curriculum module (courses) and implementation effect, to describe and drive the integration curriculum system. As shown in graph 11, implementation matrixes  $R_s$  is evaluated on a five-point scale. The first-level realization matrix has its concrete requirements and goals for all courses involved and courses goals can be deeply refined to improve the teaching reform. At the first stage of the reform, the course objectives are set as the 17 ability objectives above, which means that the target matrix of course objectives is  $A_c=A_s$ . The evaluation matrixes  $M_{ss}$ ,  $M_{se}$ ,  $M_{sg}$ ,  $M_{sc}$ ,  $P_s$  are evaluated on a five-point scale. Contribution Factors of Some Courses evaluated by students are shown in Table 2.

Under the drive of curriculum goal matrixes  $A_c$ , our college implements courses teaching reform using control system based on second-level realization matrixes which consist of curriculum goal matrixes  $A_c$ , class teaching segments (teaching methods) and teaching implementation results.  $R_c$  is designed of 5 points, used to describe and drive the integration of the curriculum teaching, and evaluation matrixes  $M_{cs}$ ,  $M_{ct}$ ,  $M_{ce}$ ,  $P_c$  are also designed of 5 points. For the whole curriculum, teaching reform practice has finished a cycle and has yielded a good results. Part of the results are shown as follows. The second-level realization matrix of course – "Processional device internship" is shown in Figure 12.

## CONCLUSIONS

CDIO engineering education reform is an integral system engineering with all aspects involved, which consists of both design and implementation problem. Studying the twelve standards of CDIO with the methods of engineering system and control theory, the paper establishes a CDIO standard control system composed of three correlated layers of courses, curriculum and cultivating mode. For the effective operation of CDIO standard control system, CDIO implementation control model is built based on the realization matrix of three elements:

cultivating objectives, implementation approaches and effects. The combination of qualitative and quantitative methods for CDIO engineering education reform system analysis and implementation is proposed. The method was applied in our college's engineering education reform and has obtained a good result. Using the quantitative method, the design and implementation problems of engineering education reform are studied in theory. Therefore, the paper is of both theoretical and practical significance.

Target Matrix of Curriculum Objectives  $A_s$

Course Module	Courses	General Engineering Competence Cultivating Objectives								Automation Specialty Competence Cultivating Objectives								
		Project Inference Ability (Recognition, Modelling, Solving)	Ability of Solving Engineering Problems with Integration of Technology and Modern Tools	Ability of Experiment & Exploring Knowledge	Ability of System Thinking	Creative & Critical Thinking	Correct Cognition of Professional Ethics & Responsibility	Correct Cognition of Life Long Learning & Learning Ability	Ability of Team Organization, Coordination & Integration	Ability of Effective Interpersonal Communication & Expression	Cognition of Impact of Global Economics, Environment	Application Ability of Math, Science & Engineering	Electronic System Design Ability	Industrial Programming Ability	Control System Analysis, Design & Simulation Ability	Control System Design & Product Integration Ability	System Installation, Debugging, Operation & Maintenance Ability	Enterprise Practice Ability
Basic Module of Electricity	.....																	
	Circuit Analysis	5	5	5					5			5						
	Analog Electronic Technique	5	5	5					5			5						
	Digital Electronic Technique	5	5	5					5			5						
Control Engineering Module	.....																	
	Electronic System Engineering Design (I,II)	5	5	5			5	5	5			5						
	Computer Process Control Engineering A	5	5	5	5				5						5	5	5	
	Computer Process Control Engineering B		5	5	5				5	5					5	5	5	
	Control System Operation & Maintenance		5	5	5				5	5					5	5	5	
	Instrument Technology Internship		5	5	5				5	5					5	5	5	
.....																		
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Figure 11. First-level realization matrix  $R_s$

Table 2. Contribution Factors of Some Courses

Course	Course Contribution Factor of Student Evaluation $f_c$
Computer Basis and Skill Training	4.4156
Circuit Analysis A	3.8115
Electronic Engineering Design (I)	3.7306
Electronic Engineering Design (II)	3.7027
Automatic Control Theory A	4.1875
Integrated Design of Control System	4.1319
Microcomputer Principle and Interface Technology	4.2606
Introduction to Automation	4.2374
Instrument Technology Internship	4.4378
Advanced Control Technology	4.1860
DSC, PLC, FCS Principle & Application B	4.1381
Computer Process Control Engineering A	3.8450
Computer Process Control Engineering B	4.2655
Process Device Internship	3.9777
Operation & Maintenance of Process Control System	4.4630

Target Matrix of Course Objectives  $A_c$

		General Engineering Competence Cultivating Objectives										Automation Specialty Competence Cultivating Objectives								
		Project Inference Ability (Recognition, Modelling, Solving)	Ability of Solving Engineering Problems with Integration of Technology and Modern Tools	Ability of Experiment & Exploring Knowledge	Ability of System Thinking	Creative & Critical Thinking	Correct Cognition of Professional Ethics & Responsibility	Correct Cognition of Life Long Learning & Learning Ability	Ability of Team Organization, Coordination & Integration	Ability of Effective Interpersonal Communication & Expression	Cognition of Impact of Engineering Problem on the Global Economics, Environment & Society	Application Ability of Math, Science & Engineering knowledge	Electronic System Design Ability	Industrial Programming Ability	Control System Analysis, Design & Simulation Ability	Control System Design & Product Integration Ability	System Installation, Debugging, Operation & Maintenance Ability	Enterprise Practice Ability		
Teaching Segment & Methods	Teaching Methods																			
	Theoretical Teaching	Lecture																		
		Laboratory Teaching	5	5	5				5	5						5	5	5		
		Seminar																		
		Project Learning	5	5	5				5	5						5	5	5		
		Self-study																		
	Practical Teaching	Personal Operation		5	5	5					5	5					5	5	5	
		Team Operation		5	5	5					5	5					5	5	5	
		Enterprise Operation		5	5	5					5	5					5	5	5	
		Project Practice		5	5	5					5	5					5	5	5	
		Independent Practice																		
	Assessment	Written Exam		5		5											5	5	5	
		Operation		5	5	5				5	5						5	5	5	
		Defence		5	5	5					5	5					5	5	5	
		Dissertation																		
		Open Test		5	5	5					5	5					5	5	5	

Figure 12. The second-level realization matrix of the course – “Process Device Internship”



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