Research and Exploration of Engineering Courses
Based on Ability Realization Matrices

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Keywords: Ability realization matrices, Engineering education, Outstanding engineers plan.

Abstract. Ability realization matrices model of ability training goal, realization mode and learning output as coordinate is established, based on the educational accreditation standard of engineering education; The ability training-oriented curriculum teaching system is reconstructed, according to ability training requirements of Outstanding Engineers Plan; Quantitative evaluation of the learning output is completed by the closed-loop feedback control and analysis of teaching quality; At last, aiming at the practical problems in engineering education, the curriculum teaching reform and exploration based on the ability realization matrices model is implemented to improve the ability of engineering application and innovation.

Introduction
With the deepening of the reform of higher education, the cultivation of the ability for innovation and entrepreneurship of students majoring in engineering has become an important direction for the reform of curriculum teaching. In 2016, China formally acceded to the “Washington Accord”. “Being able to apply mathematics, science and engineering knowledge in the process of system, process and machine design, operation and improvement, while find and solve complex engineering problems”, which is the key to the cultivation of engineering professional ability. At present, the existing teaching system and methods of mechanical engineering major courses cannot achieve the goal of the cultivation of students' innovation ability. Moreover, the teaching of courses is far from engineering practice. Therefore, there is an urgent need to construct a curriculum system and teaching method which is being based on the objectives of the capacity building while could evaluate effectively. Accordingly, based on the concept of “new engineering” cultivation mode, this paper puts forward a teaching system based on the ability to realize the matrix model, establishes a quality control model and its practical operation method, with “learning output” as the goal. Meanwhile, in order to improve students' awareness of engineering, analysis and problem-solving ability and engineering innovation ability.

Establishment and Practice of Ability Realization Matrices
The teaching mode of mechanical specialty course needs to be transferred from the traditional “Knowledge Transfer-oriented” to “Capacity-building-oriented”. Therefore, based on the current domestic and abroad research results, the goal of “Learning Output” is to establish an ability realization matrices model of the relationship between ability and curriculum, then apply it in practice of specific courses.

Review of Related Studies
The learning output is the concept of cultivation that the knowledge, ability, quality and personality which students mastered after graduation, which is put forward by the foreign higher education. One of the important methods of this concept is to associate the curriculum with the learning output[1]. The United States Engineering and Technology Certification Committee ABET, the British Higher Education Quality Assurance Bureau QAA and other foreign management institutions take learning
output as the main means of engineering certification, the quality assessment based on input indicators is changing gradually to the results evaluation and performance evaluation direction, more emphasis on the output and value-added courses teaching\(^2\). Shouping. Hu and George. D. Kuh put forward the model of influencing factors of learning output, set up four variables: Students' input, students’ effort, school investment and students' learning achievement. Students' input is the basis of their study, while through individual efforts and the school education’s effect, students will obtain certain learning achievement \(^3\). Therefore, domestic paper puts forward a new viewpoint and reform plan about the cultivation mode and method of engineering curriculum ability in China. In the process of implementing curriculum teaching reform, Feifan Ye has set up a mapping table of curriculum and specialty training goals, and connected the particular teaching process, teaching methods, assessment methods and training goals with the teaching implementation effect, then reconstructed the new curriculum system \(^4\). In the process of teaching particular practice, Jianfeng Yu and so on tried to take the ability training of process equipment and control majors’ students as the guidance, while through constructing ability matrix model, to improve students' engineering technical ability comprehensively \(^5\).

To sum up, paying attention to the effect of teaching implementation is of great significance to the guidance of transformation from “knowledge imparting leading mode” to “ability training leading mode”. The ability training standard realization matrix connects the ability training goal, the curriculum particular teaching and the examination method, analyzes the teaching influence law and the significance relations to the ability training goal, finally forms the continuous improving positive feedback closed-loop quality control system, promotes the continual enhancement of the curriculum teaching quality.

**The Ability Realization Matrices for Engineering Courses**

The curriculum ability realization matrices model (output model) of curriculum capability is shown in Figure 1. The two-dimensional matrix space of the model is composed of the curriculum ability realization mode and the curriculum ability training standard. The two-dimensional space is the design space of the curriculum teaching scheme. Meanwhile, Ability training objects (Y axis) and the ability realization mode (X axis) are interrelated. As a learning output (z-axis/fraction) and two-dimensional space, ability evaluation has finally formed a practical model of evaluating the effect of curriculum ability cultivation.

The purpose of ability training program based on curriculum output model to develop curriculum teaching is to pursue the maximum value of learning output in two-dimensional space. The two-dimensional space of the output model can be expressed in matrix form, and the numerical value of the matrix element indicates the effect of the implementation of the design of a culture standard, which is the learning output (percentile).

![Figure 1. The curriculum ability realization matrix model (output model).](image)

**The Curriculum Practice Based on Ability Realization Matrices**

About the requirements of ability cultivation for outstanding engineers in engineering education. For example, “the National Accreditation standard for undergraduate education in mechanical engineer”
is divided into 3 categories of 9 capacity requirements (table 1), issued by the Teaching and Research Center of Universities and the Steering Committee of Mechanical Discipline, which corresponds to the United States Engineering and Technology Accreditation Committee ABET proposed 11 competencies required by outstanding engineer (table 2) \(^{[6,7]}\).

<table>
<thead>
<tr>
<th>Engineering analysis Capability</th>
<th>(1) Ability to apply the knowledge of mathematics, natural science and mechanical engineering;</th>
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<tr>
<td></td>
<td>(2) Ability to establish experimental programs, conduct experiments, analyze and interpret data;</td>
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<td></td>
<td>(3) Ability to design mechanical systems, components or processes according to requirements;</td>
</tr>
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<td></td>
<td>(4) Ability to express, model, analyze, solve and demonstrate mechanical engineering problems;</td>
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<td></td>
<td>(9) Have consciousness of lifelong education and continuous learning ability;</td>
</tr>
<tr>
<td>Resource integration Capabilities</td>
<td>(5) Master the ability to utilize a variety of technology, skills and modern engineering tools in mechanical engineering practice;</td>
</tr>
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<td></td>
<td>(7) Ability to play a role in multi-disciplinary team. Strong interpersonal communication skills;</td>
</tr>
<tr>
<td>Social responsibility capacity</td>
<td>(6) Have social responsibility and consciousness of professional ethics;</td>
</tr>
<tr>
<td></td>
<td>(8) Master knowledge of modern social problems, which is sufficient to understand the impact of mechanical engineering on the world and society.</td>
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</table>

Table 2. United States engineering and technology accreditation committee ABET ability classification \(^{[7]}\).

<table>
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<tr>
<th>Engineering analysis Capability</th>
<th>(1) Ability to apply mathematics, science and engineering knowledge;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(2) Ability of design, experiment analysis and data processing;</td>
</tr>
<tr>
<td></td>
<td>(3) Ability to design a component, a system or a process if needed;</td>
</tr>
<tr>
<td></td>
<td>(9) Ability to learn life-long;</td>
</tr>
<tr>
<td>Resource integration Capabilities</td>
<td>(4) Comprehensive ability of training;</td>
</tr>
<tr>
<td></td>
<td>(5) Ability to verify, guide and solve engineering problems;</td>
</tr>
<tr>
<td></td>
<td>(7) Ability to express and communicate effectively;</td>
</tr>
<tr>
<td></td>
<td>(11) Ability to apply various technologies and modern engineering tools to solve practical problems</td>
</tr>
<tr>
<td>Social responsibility capacity</td>
<td>(6) Knowledge of professional ethics and social responsibility;</td>
</tr>
<tr>
<td></td>
<td>(8) Understand the impact of engineering problems on the global environment and society;</td>
</tr>
<tr>
<td></td>
<td>(10) Knowledge of the problems of the present age.</td>
</tr>
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</table>

The two-level index, which corresponds to ability training standard, includes three sections of theory teaching, practice teaching and examination. Theoretical teaching has the ability cultivation mode such as classroom teaching, case teaching, thematic discussion, and so on. The practical teaching includes personal operation, group practice and so on. In order to strengthen the ability assessment of students' learning process, the course examination method is composed of examination, homework and experiment. Corresponding to different levels of different indicators, it could adopt different implementation methods, next come out different levels of different types of design space. These design space can be mapped to the practice space, then get the implementation of various teaching design results. This process can be represented by different ability realization matrices, through implementing the operation of matrix, the transformation, combination and decomposition of different design space and implementation space can be carried out to realize the quantitative analysis, design, evaluation and appraisal of the teaching reform practice, finally put forward the ideas and methods of innovation education reform \(^{[2]}\). According to the training goal of curriculum ability, designing ability realization matrices, it is necessary to realize the teaching effect of ability cultivation to ensure the quality of teaching.

**Reconstruction of Curriculum System and Quality Control**

**Reconstruction of Curriculum System**

As shown in Figure 2, goals of curriculum ability training, teaching quality control loop and learning output sets of curriculum ability constitute the control model of curriculum quality.
In the model, according to the certification standard of mechanical engineering professional ability, the goal of curriculum ability training is determined; the curriculum system is reconstructed, the teaching quality control loop is designed; the learning output of students is evaluated according to the ability training goal, in order to judge whether it can reach the ability training standard.

**Curriculum Teaching Quality Control Loop**

The design of the curriculum teaching quality control loop is the basis of reconstructing the whole curriculum system and realizing the goal of ability training, which is also the key to improve the teaching quality of the course, which is the most workload, the quickest and the most practical control segment. As the course quality control model shown in Figure 3, according to the curriculum ability cultivation target \( O_c \), it aims to explore the teaching content, teaching method and teaching means of this course, construct the ability realization matrix \( R_c \); establish curriculum syllabus, implement curriculum teaching reform and quality control, adopt students, teachers, experts and other diverse evaluation methods to assess the realization of teaching ability goals, which is learning output. To get the curriculum goal evaluation matrix \( P_c \), according to the deviation matrix \( E_c \) and diversity evaluation difference matrix \( D_c \), adjust the two-level achieved matrix \( R_c \), revise curriculum syllabus, further adjust curriculum teaching syllabus, then further adjust course teaching, finally continuously promote and implement the curriculum teaching reform.

\[
O_c \rightarrow E_c \rightarrow R_c \rightarrow C_c
\]

**Figure 3. Quality control loop of course teaching.**

It is assumed that the pluralistic evaluation matrices of course teaching are: \( M_s \), \( M_t \) and \( M_e \), moreover, the corresponding weight coefficients are: \( \alpha_s \), \( \alpha_t \) and \( \alpha_e \);

Therefore, the measurement matrix of the target realization of teaching ability is:

\[
M_c = \begin{bmatrix} 1 & 1 & \ldots & 1 \end{bmatrix}_{\alpha_s} \cdot [\alpha_s \cdot M_s + \alpha_t \cdot M_t + \alpha_e \cdot M_e] / 3
\]

(1)

The evaluation matrix of curriculum target ability realization is:

\[
P_c = [M_c(1)/b_1, \ M_c(2)/b_2, \ldots, \ M_c(n)/b_n] / 3
\]

(2)

Order \( b_i \) for the number of non-0 elements in column \( i \) of \( M_c \).

The difference matrix of curriculum objective evaluation:
Course target deviation Matrix:

\[ D_{c1} = M_c - M_t ; \quad D_{c2} = M_t - M_e ; \quad D_{c3} = M_e - M_c \]  

(3)

\[ E_c = O_c - P_c \]  

(4)

Quality Control and Analysis

Based on the model of curriculum teaching control loop, establishing the target \( O_c \) of curriculum ability cultivation, constructing the ability realization matrix \( R_c \) is the top level design of classroom teachers; the evaluation matrix \( P_c \) of course target is the measure evaluation of course target output\(^{[2]}\).

(1) The weight analysis of the realization mode of curriculum ability

The realization of students' ability go through theoretical, practice teaching and assessment, such as the completion of the process, such as the assessment of the design of various assessment methods, which formed the ability realization matrix \( R_c \). While according to the ability cultivation standard output of the contribution and effectiveness, it modify ability realization matrix, then realize the quality control of the course loop, finally realize the goal of curriculum ability cultivation.

(2) The weight analysis of curriculum ability cultivation standard

Based on the cultivation target matrix \( O_c \), the two-level index system is established, and the weights of each index are different. According to the training goal of curriculum ability and the actual situation of teaching, classroom teachers set the corresponding weights. Meanwhile according to the feedback result of the course goal evaluation, optimize ability realization matrix model, and unifies the curriculum reform need as well as the teaching actual result.

(3) The relativity analysis of the goal and realization mode of the curriculum ability cultivation

To construct the course goal evaluation matrix \( P_c \), it need to consider the subjective uncertainty factors of the course actual evaluation process, so we can introduce the mathematical statistic method to carry on the correlation analysis, then optimize the teaching method and examination means.

(4) Analysis of the weights and differences of curriculum ability evaluation

In the curriculum teaching pluralistic evaluation matrix, the students' evaluation matrix \( M_s \), the teachers’ evaluation matrix \( M_t \) and expert evaluation matrix \( M_e \) are different. The course teaching quality control process needs to determine the weight coefficient rationally and reduce the difference of course evaluation, in order to improve the accuracy and reliability of the evaluation result of the students’ curriculum ability continuously.

Conclusion

The teaching reform and quality improvement of engineering education is a systematic project, which must be closely related to the improvement innovation ability for outstanding engineer, which enrich the content of courses, increase the practice link, and strengthen the connection between the course system and engineering application. The paper studies theoretical and practical problems, establishes the three-dimensional space based on the ability to realize the matrix model based on the ability to train the target, the realization mode and the learning output are coordinates, provides the theoretical framework for the quantitative control of the curriculum teaching quality and the practical implementation method of the curriculum, and carries out the practice and exploration of the curriculum teaching reform for the practical problems existing in the course teaching.

Acknowledgement

This research was financially supported by the Education and training Program for Excellence Engineers. (Letter of Higher Education Department, Ministry of Education, China: No. 7, 2010)
References


