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Construction of an engineering and technology practice system for professional graduate students based on ISM

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ABSTRACT: With a questionnaire method and stratified random sampling, the authors have completed a questionnaire survey of components and their relative proportions in an engineering and technology practice system for professional graduate students. The result of the questionnaire survey was true and valid. The analysis of the questionnaire showed practical links and representative components of the system. Meanwhile, based on the multiple iteration programmed through Matlab 7.0, the authors have obtained the interpretive structural model (ISM) of the engineering and technology practice system for professional graduate students. Levels of the model were revealed by the diagrams in three links - direct, indirect and core practice links, and the logical relation between the elements was indicated through multi-level hierarchical analysis. Finally, the advantages and limitations of the ISM model were discussed for the determination of the authors' further research.

INTRODUCTION

As the highest level of education, graduate education has an important role to play in the social development of China. It is part of the construction of a powerful innovation-oriented and human-resource rich nation. With the rapid development of modern technology and society, professional degrees are being introduced for the cultivation of applied talent, who can engage creatively in practical work, showing professional ability and quality. It has the characteristics of directionality, professionalism and practicality, to meet social requirements [1].

Students in professional degree education can systematically grasp advanced specialised knowledge and have the ability to solve problems in a specific occupational area. Therefore, professional degrees always have a strong industrial or professional background [2].

Due to specific professional directionality, every type of professional graduate education in China has a different training objective and method, according to the guidance of educational instruction committees. Compared with an academic graduate degree, the model for professional graduate degrees is more flexible and various, with practical education characteristics [3].

Given the training objective of professional graduate education, training units have to fully prepare graduates to meet the requirement of their future occupational positions. The improvement of engineering and technology graduates' ability to practice is a necessary part of a professional graduate student's professionalism driven by the intensification of professional directionality. Currently, the forms of engineering and technology practice for professional graduate students include school-arranged practice bases, advisor-recommended or student-negotiated enterprises, and other scientific research projects [4-5].

Most professional graduate students are full-time students in China. These students lack life experience and have imperfect professional modes of thinking and practical ability. The development of their internal potential is an urgent project, considering their weak engineering and technology consciousness. Therefore, noting the training model of professional graduate students, a practical engineering and technology practice system was constructed, with professional degree education characteristics taking account of the employment situation.

INTERPRETIVE STRUCTURAL MODELLING

Interpretive structural modelling (ISM) is an analysis method proposed by Professor J. Warfield of the USA in 1973. In this modelling system, the incidence matrix of graph theory is used to analyse the whole structure of a complex system and logic diagrams are applied to describe the relationship between elements in the system [6]. With a system model to represent the integration of elements, the complex system is divided into several subsystems based on certain methods. Meanwhile, combined with practical experience and knowledge, a multi-level hierarchical structure model is established using computer application technology. Due to the clear interrelation of internal elements, the model has been widely applied in such fields as energy, resources, environment, economy and medical treatment. It is suitable for most system engineering phases, such as goal determination, planning, analysis, comprehensive evaluation and decision-making [7-8].

The analysis steps of ISM include:

1. determination of system elements;
2. establishment of the adjacency matrix;
3. derivation of the reachability matrix;
4. partition of the hierarchical structure;
5. construction of the ISM model;
6. multi-level hierarchical analysis.

COMPONENTS OF THE ENGINEERING AND TECHNOLOGY PRACTICE SYSTEM FOR PROFESSIONAL GRADUATE STUDENTS

In this work, stratified random sampling was conducted in several units, such as education departments, human resources and social security bureaus, placement offices, universities and vocational technical colleges, large state-owned enterprises, foreign companies and mass-run enterprises. The respondents included educators, career experts, graduates, undergraduates and employees in enterprises.

The authors researched the components and their corresponding relative proportions in engineering and technology practice systems for professional graduate students.

The authors distributed 400 questionnaires in toto and 394 were returned. After the elimination of invalid questionnaires (with wrong answers, incomplete information and missing data), there were 382 effective questionnaires for a return ratio of 95.5%. Therefore, the questionnaire survey was adequate and effective, objectively meeting the research requirements. The analysis of the 382 questionnaires indicate there are mainly three practice links and 10 representative components in the engineering and technology practice system for professional graduate students (Table 1).

Table 1: Representative components of engineering and technology practice system.

No.	Practice links	Symbol	Representative components
1	School practice	s_1	Scientific research and academic exchanges
2		s_2	Application for open experiments
3		s_3	Dissertation writing
4	School-enterprise training	s_4	Enterprise practice
5		s_5	Guidance by enterprise mentors
6		s_6	Product research and industrialisation
7	Innovation and entrepreneurship training	s_7	Longitudinal projects
8		s_8	Co-operation of crosswise projects
9		s_9	Innovation projects
10		s_{10}	Entrepreneurship programme training

It is shown that the three practice links include school practice for the improvement of practical operational capacity, school-enterprise training for the introduction of graduates to enterprises, and innovation and entrepreneurship training for the improvement of enterprise consciousness and scientific research capacity.

The ten representative components include scientific research and academic exchanges, application for open experiments, dissertation writing, enterprise practice, guidance by enterprise mentors, product research and industrialisation, longitudinal projects, co-operation of crosswise projects, innovation projects and entrepreneurship programme training.

ISM OF THE ENGINEERING AND TECHNOLOGY PRACTICE SYSTEM FOR PROFESSIONAL GRADUATE STUDENTS

The three practice links and ten representative components make up the elements of the practice system. Each element has direct or indirect effects on other elements. Here, with the ten elements as research objectives, the engineering and technology practice system for professional graduate students was constructed based on ISM and the hierarchical structural relationship between elements was analysed.

Determination of System Elements

Suppose that n is the number of system elements and S_i is one system element, where n = 1,..,10 and $S_1 \sim S_{10}$ are the ten components. Then, the set of system elements is:

$$S = \{ s_i \mid i = 1, 2, \cdots, n \} \tag{1}$$

Establishment of the Adjacency Matrix

Let a_{ij} be the direct binary relation between elements of the set, then, the adjacency matrix A = $(a_{ij})_{M \times N}$,

where a_{ij} is defined by Zhou et al [9]:

if a_{ij} = 1 and $i \neq j$, then, there is a direct relationship binary between element *ei* and *ej*;

if a_{ij} = 0 and $i \neq j$, then, there is no direct binary relationship between element *ei* and *ej*;

The matrix A becomes:

$$A = (a_{ij})_{M \times N} = \begin{bmatrix} 0&0&0&0&0&0&0&0&0&0 \\ 1&0&0&0&0&0&0&0&0&0 \\ 1&0&0&0&0&0&0&0&0&0 \\ 1&0&0&0&1&1&0&1&1&1 \\ 1&0&1&0&0&0&0&0&1&1 \\ 1&0&0&0&0&0&0&0&0&0 \\ 1&0&0&0&0&0&0&1&1&1 \\ 1&0&0&0&0&0&0&0&0&0 \\ 1&0&0&0&0&0&0&1&0&1 \\ 1&0&0&0&0&0&0&0&1&0 \end{bmatrix} \tag{2}$$

The Reachability Matrix

To derive the Reachability Matrix M, the matrix A is summed with the unit matrix I, and the reachable matrix M is obtained by multiple iterations based on the Boolean operation [10].

$$(A+I)^n = (A+I)^{n+1} \Rightarrow M = (A+I)^n \tag{3}$$

The Boolean operation is described by Lu and Pei [11]:

$$(0+0=0, 0+1=1+0=1, 1\times 0=0\times 1=0, 1+1=1, 1\times 1=1) \tag{4}$$

After programming with Matlab 7.0, the solution for M is:

$$M = \begin{bmatrix} 1&0&1&0&0&0&0&0&0&0 \\ 1&1&0&0&0&0&0&0&0&0 \\ 1&0&1&0&0&0&0&0&0&0 \\ 1&0&1&1&1&1&0&1&1&1 \\ 1&0&1&0&1&0&0&1&1&1 \\ 1&0&0&0&0&1&0&0&0&0 \\ 1&0&0&0&0&0&1&1&1&1 \\ 1&0&0&0&0&0&0&1&0&0 \\ 1&0&0&0&0&0&0&1&1&1 \\ 1&0&0&0&0&0&0&1&1&1 \end{bmatrix} \tag{5}$$

Partition of Hierarchical Structure

The solution for the highest-level element set in the multi-level hierarchical structure is described by Fu at al [12]:

$$L_1 = \left\{ S_i \middle| P(S_i) \cap R(S_i) = P(S_i) \right\}; i = 0, 1, \cdots, k\} \tag{6}$$

where $P(S_i)$ is a reachable set-combination of all column elements equal to 1 in line S_i and $R(S_i)$ is an advanced set-combinations of all line elements equaling to 1 in column S_i. After the deletion of the corresponding line and column of L_1 in the reachable set *M*, a new reachable set *M'* is obtained and its solution of the new highest-level element set is derived.

Proceeding as above, the highest-level element set of each level is obtained.

$$L_1 = \{S_2, S_5, S_8\},\ L_1 = \{S_6, S_7, S_{10}\},\ L_2 = \{S_1, S_3, S_4, S_9\} \tag{7}$$

Then, the lines and columns of reachable sets are rearranged based on the partition results with element levels. After the element connection of adjacent levels and the same levels, the level structure of the engineering and technology practice system for professional graduate students is obtained as:

$$N = \begin{array}{c} \\ S_2 \\ S_5 \\ S_8 \\ S_6 \\ S_7 \\ S_{10} \\ S_1 \\ S_3 \\ S_4 \\ S_9 \end{array} \left[\begin{array}{cccccccccc} S_2 & S_5 & S_8 & S_6 & S_7 & S_{10} & S_1 & S_3 & S_4 & S_9 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 1 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 1 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 & 1 & 0 & 0 & 0 & 1 \end{array} \right] \tag{8}$$

Construction of the ISM Model

The ten elements of element sets L_1, L_2 and L_3 present representative practice links in the engineering and technology practice system for professional graduate students. There is a certain logical relational chain between the levels of elements. After the connection of elements in adjacent levels, the ISM model was obtained that could clearly show the relations of all elements (Figure 1).

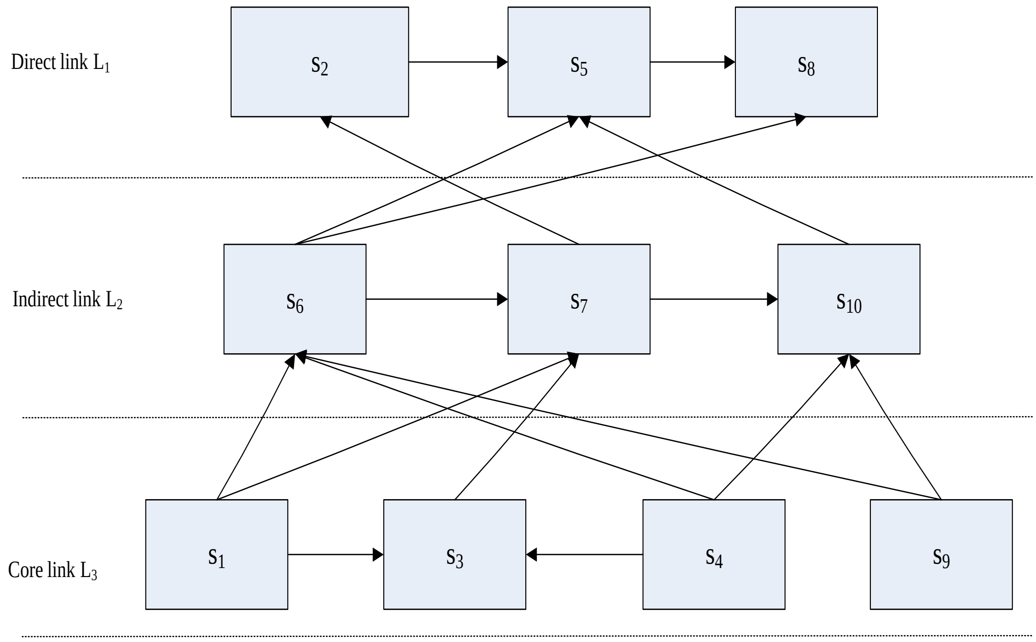

Figure 1: The ISM model.

Multi-level Hierarchical Analysis

In Figure 1, there are three structure levels in the ISM model of the engineering and technology practice system for professional graduate students, and the direction arrows indicate the logical relation and interrelation between each element at each level in the ISM model.

As the first level, direct practice links include application for open experiments, guidance of enterprise mentors and co-operation of crosswise projects. Among these, application for open experiments relies on scientific research institutions and school laboratories with strong scientific research ability. It combines superior resources of engineering and technology with subject construction achievements and mediums, such as scientific research platforms and practice teaching platforms.

The purpose of open experiments is to create an atmosphere of scientific research and to improve graduate students' enthusiasm for research. For the guidance of enterprise mentors, experienced senior experts will be employed as mentors to jointly manage and guide several practice links of students, such as in engineering practice, scientific experiments and academic dissertations. For the co-operation of crosswise projects, graduate students will be recommended to co-operation units for professional practice. With further knowledge of the application of research achievements in practice, students are expected to improve their ability in scientific research, analysis and problem-solving.

The second level, indirect practice link includes three elements of product research and industrialisation, longitudinal project research and entrepreneurship programme training. Product research and industrialisation refers to the research co-operation of school mentors and enterprise mentors. Students will be guided toward joining the engineering practice of technical innovation and product research. With the final marketisation and industrialisation process for new products, these students can improve their engineering skills in design research, manufacturing technique and performance examination. In longitudinal project research, students will complete their task assignment, topic selection of academic dissertation, planning of scientific research and the testing programme, all based on various longitudinal projects of mentors.

The training in engineering consciousness and research innovation ability, makes the organic integration of research practice and applied graduate education more likely. For entrepreneurship programme training, student teams will be funded to develop their promising technical products or service concepts in organised business plan competitions. Aiming to obtain venture investment, students have to complete a business proposal including company introduction, business and its prospects, risk factors, return on investment, exit strategy, organisation and management and financial forecasting.

There are four elements in the third-level core practice link, including academic exchanges, dissertation writing, enterprise practice and innovation projects. Graduate students are required to have regular academic exchanges in research groups around research links, such as topic selection, project design, project approval, implementation, achievement presentation, acceptance assessment, and the application of achievements.

With the understanding of research status and advanced research, students can realise gaps in their abilities and improve their own scientific research; and finally, gaining more experience of engineering practice through teamwork. For dissertation writing, students have to select a design topic under the guidance of school mentors and enterprise mentors, based on professional background, practice experience, school mentors' project, enterprise mentors' research or solutions to engineering practical problems.

Enterprise practice of training units provides opportunities to improve students' application ability and comprehensive practical ability, as well as to promote the combination of production, education and scientific research. Additionally, under the guidance of mentors, students who are deeply interested in scientific research and invention will be funded to complete their research process, including self-selection of topic, self-design, self-experiment and self-management. With free development space and innovative platforms, these students can improve their engineering consciousness and engineering practice ability.

CONCLUSIONS

Stratified random sampling was adopted in the questionnaire survey of components and corresponding relative proportions in the engineering and technology practice system for graduate students. With an effective return ratio of 95.5%, the results are effective in meeting the research requirements. Meanwhile, the analysis of the 382 questionnaires indicates there are mainly three practice links and 10 representative components in the system.

Based on the basic principle of the ISM model, the authors used Matlab 7.0 to write an operational program for multiple iterative computations. The authors obtained the ISM model of the engineering and technology practice system for graduate students. The diagram reveals the three levels of the model - direct, indirect and core practice links. Meanwhile, the logical relation between each element was explained through multi-level hierarchical analysis.

The ISM model shows a clear interrelation between internal elements by its division of a complex system into several subsystems. However, the ISM model has a precondition, i.e. subjective qualitative analysis, and its original data were from questionnaires with a limited sample size. In addition, binary representation was used in the establishment of the adjacent matrix, solution of the reachability matrix and partition of the hierarchical structure. These measures mean there are certain limitations for the results of survey and analysis. Therefore, the authors will introduce several quantitative analysis methods, such as neural network, grey theory, analytic hierarchy process and genetic algorithms in future research. The engineering and technology practice system for graduate students will be further perfected through the combination of qualitative and quantitative methods.

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