Analysis of Knowledge Network Atlas of Undergraduate Education Curriculum System from the Perspective of Complex network

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Abstract. Based on the theory of complex networks, this article establishes a knowledge network model for the undergraduate course system of electrical engineering, which is related to the common graduate ability training goals of various courses that meet the certification standards for engineering education, and analyze the statistical characteristics of the network. This article explores the interrelationships between various courses in the professional training program related to graduation requirements, explores the structural patterns inherent in the curriculum system, and provides new ideas for the construction and improvement of the undergraduate curriculum system in universities.

Keywords: Knowledge network atlas, Undergraduate Education, Curriculum System, Complex network

1 Introduction

The scientific and effective nature of the professional curriculum system is the key to the quality of student training in universities.The formulators of undergraduate professional curriculum system in universities are often experience driven and lack scientific and quantitative research when specifying course systems, arranging course content, course credits, and scheduling course semesters[1].The position and role of courses in the knowledge system, especially when considering students' graduation ability requirements, may not be fully understood by the director.

The rise of network science has provided new ideas for the construction and improvement of undergraduate curriculum system in universities. For example, two professors from Johns Hopkins School of Medicine in the United States proposed a new model for graduate teaching curriculum arrangement, which uses a network of nodes and edges to integrate key information of biological knowledge, allowing students to better grasp the course knowledge they have learned[2]. This article draws inspiration from this approach and, based on complex network theory[3][4], takes the training plan for undergraduate students majoring in Electrical Engineering at Changsha University of Technology as an example to explore the correlation between professional courses, excavate the core courses with the greatest dissemination and influence in the course structure, and use visual tools of network analysis to visually present

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the correlation between various courses in the training plan related to graduation requirements. This study attempts to provide a more intuitive and quantitative perspective for quantitatively evaluating core professional courses and exploring the structural patterns inherent in the curriculum system.

2 Knowledge Network Modeling

This study selects the courses in the undergraduate course system of Electrical Engineering at Changsha University of Technology as nodes, and constructs a weighted undirected graph $G=(V, E)$ based on the graduation ability requirements of students as the connection between the courses. Among them, $V=\{v_1,v_2,v_3,...,v_n\}$ is the set of nodes in the network, with each node representing a course; $E=\{a_{ij}|i,j=1,2,...,n\}$ is the set of node associations, where a_{ij} is the edge between nodes v_i and v_j. The course collection selected for this study is shown in Table 1.

Referring to the Graduate Attribute Profiles proposed in the Washington Accord [5][6], we have summarized 12 graduate competency requirements that meet the certification standards for engineering education in China, as follows:

- Professional norms(PN): Love the Country, have a sense of social responsibility, possess humanistic and social science literacy, and fulfill responsibilities;
- Engineering knowledge(EK): able to apply mathematical, natural science, and engineering expertise to solve complex engineering problems;
- Problem analysis(PA): Able to identify, express, and analyze complex engineering problems through literature research to obtain effective conclusions;
- Design/Develop Solutions(DD): Able to design solutions for engineering problems while considering social, legal, cultural, and environmental factors;
- Research(RS): Able to use scientific methods to study complex engineering problems;
- Using modern tools(UT): Able to develop, select, and use appropriate technologies, resources, and modern tools to solve complex engineering problems;
- Engineering and Society(ES): Able to evaluate the impact of engineering solutions on society, health, safety, law, and culture;
- Environment and Sustainable Development(EV): Able to understand and evaluate the impact of engineering practices on environmental and social sustainable development;
- Individuals and Teams(IN): Possess teamwork spirit and the ability to play a role in a multidisciplinary context;
- Communication(CM): Able to communicate and collaborate with peers and the public, and able to collaborate in cross-cultural contexts;
- Project management(PM): Understand and master the basic knowledge of engineering management principles and economic decision-making methods;
- Lifelong learning(LL): Having the awareness of autonomous learning and lifelong learning.

Each course in the curriculum system needs to support the above graduation requirements. The corresponding relationship matrix between courses and graduation requirements is shown in Table 1.

TABLE 1. Correspondence matrix between courses and graduation ability requirements

Course No.	Course Name	Graduation ability requirements											
		PN	*EK*	*PA*	*DD*	*RS*	*UT*	*ES*	*EV*	*IN*	*CM*	*PM*	*LL*
1	College English										H		
2	Higher Mathematics		H										
3	Engineering Drawing		M	M	H		H						
4	linear algebra		H										
5	Ideological cultivation and legal foundation	H			L			L	M	M			
6	Fundamentals of Computer and Programming						H						
7	Physical Education	H								L	L		L
8	military training							L		M	L		
9	Psychological Health of College Students	L			L		L	H		M	M		M
10	Guidance on Learning Methods for College Students							L	L	L			
11	Introduction to Electrical Engineering						L	L			L		
12	Complex Function and Integral Transformation		H										
13	College Physics		H										
14	Circuit Theory		H	M	M								H
15	Electrical Testing Technology Experiment			M	M					H			
16	Outline of Modern Chinese History	H			L			L					
17	Engineering Cognitive Training	L					M	M	M	M			
18	Military theory									M	M		L
19	Fundamentals of Programming Application			L		M							M
20	Introduction to Mao Zedong Thought	H					M	M	M				
21	Engineering English Listening and Speaking	M						L	L		M		L
22	electromagnetic field			H	L			M					
23	Electrical Engineering A			H	L			L	H				
24	College Physics Experiment	M	H	M	L	M	L	L		L			
25	Probability Theory and Mathematical Statistics		H										
26	College Applied Chinese										M		
27	Analog Electronic Technology			H	M								
28	Digital Electronic Technology			H	M								
29	Electronic Testing Technology Experiment	L					H			H	H	M	L
30	Basic Principles of Marxism	H						M	M	M			
31	Electrical Technology Internship	M	L	L	L	L	M	M	M	M	M		M
32	Engineering Training	L					M	M	M	M			
33	Fundamentals of Entrepreneurship							M	M	M			
34	Simulation software Matlab and its application	M	M				H						
35	Power Plant Power Section	M	M		L		L	M	L				
36	General Engineering English Reading and	M						L	L		M		L

Course No.	Course Name	Graduation ability requirements											
		PN	*EK*	*PA*	*DD*	*RS*	*UT*	*ES*	*EV*	*IN*	*CM*	*PM*	*LL*
	Writing												
37	Steady state analysis of power system			H	M	M							
38	Automatic Control Principle			M	H	M							
39	Principles and Applications of Microcomputers				H		M						
40	Cognition Internship				M	L			M	H	M		M
41	Course Design for Power Grid		H	L	H	H	L		H	H	H	H	H
42	Power Electronics Technology			H	M	M					H		
43	Principles and Applications of Microcontrollers				H		M						
44	Engineering Mechanics	L											
45	Power Plant Electrical		M	H	H	L			L				
46	Transient analysis of power system			H	H	M							
47	principles of Relay Protection			M	H	M							
48	High voltage technology			L	H	H		H	H				
49	Automatic Control Technology of Power System			H	M								
50	Course Design for Power Plants		H	H	H	H	H		H	H	H	H	H
51	Electrical Engineering CAD Technology	M	M		L	M	L	L	L				
52	Course Design of Relay Protection		H	L	H	H	H		H	H	H	H	H
53	Professional Comprehensive Internship	H			M	L			M	H	H		H
54	Microcomputer protection	M	M		L		L	L	L				
55	Professional English	M					L	L	L		M		L
56	Electricity Technology Economy and Management	L		L								H	
57	Electric Energy Measurement Technology			H	M	M							
58	Power Engineering Budget	H		H	H							H	
59	Lectures on New Power Technologies			H	M	M							
60	Large unit protection			H	M	M							
61	Distribution network automation			H	M	M							
62	Automation of power system dispatch			H	M	M							
63	Power system planning			H	M	M							
64	Graduation Design	L	M	H	H	H	H	H	H	L	H	H	H

As shown in Table 1, the correlation between the course and graduation requirements is represented by "H (high)", "M (medium)", and "L (low)", respectively. For ease of calculation, the weight of H can be assigned as 3, the weight of M can be assigned as 2, and the weight of L can be assigned as 1.

According to the corresponding relationship matrix between each course and graduation requirements, the association between courses can be determined through the adjacency matrix $A=(a_{ij})_{N\times N}$. The association rule is that if there is a common graduation requirement indicator between the i-th and j-th courses, there is an undirected edge between the two courses. The element aij in the i-th row and jth column of the adjacency matrix A is defined as equation (1) shown:

$$a_{ij}=\begin{cases}0\ , & If\ no\ connection\ between\ \ i\ and\ \ j\\ w_{ij}\ , & Else\end{cases} \tag{1}$$

Which indicates the degree of correlation between the i-th course and the j-th courses. In the formula, w_{ij} is the weight of the edge connecting the i-th course and the j-th courses, which is the minimum sum of the common terms of the two courses and the graduation requirements in the relationship matrix, and can be calculated by equation (2):

$$w_{ij} = \sum_{T=1}^{12} Q^T \times Min\left(C_i^T, \ C_j^T\right) \tag{2}$$

In the formula, T corresponds to the graduation ability requirement item mentioned above, and its value range is [1,12]; The description is the weight value corresponding to the i-th course of the graduation indicator T, and Q is the weight of the 12 graduation ability requirements which was given in Table 1.

The correlation between the 64 courses shown in Table 1 can be represented by a 64 × 64 Adjacency matrix:

$$A = \begin{bmatrix} a_{1,1} & \cdots & a_{1,64} \\ \vdots & \ddots & \vdots \\ a_{64,1} & \cdots & a_{64,64} \end{bmatrix} \tag{3}$$

Each row in the matrix $a_i=\{a_{i,1},a_{i,2},a_{i,3},\ldots,a_{i,64}\}$ represents the weight value of the connection between the i-th course and each other course(including the i-th course itself). Taking the engineering drawing course in the third row of Table 1 as an example, if there is a common graduation requirement indicator term between engineering drawing and the j-th course, the minimum weight value of the common term is recorded as the weight value of the edge connecting engineering drawing and that course. As a result, through table (1), equation (1) and equation (2), The third row value of the matrix can be calculated as:

$$a_3 = \left\{ \begin{array}{c} 0,2,0,2,1,3,0,0,2,0,1,2,2,6,4,1, \\ 2,0,1,2,0,3,3,3,0,0,4,4,3,0,5,2, \\ 0,5,4,0,4,5,5,2,7,4,5,0,7,5,5,4, \\ 4,10,4,9,2,4,1,1,4,5,4,4,4,4,4,10 \end{array} \right\}$$

Similarly, the relationship matrix vectors corresponding to all courses can be calculated. According to the adjacency matrix, the course network graph can be obtained as shown in Figure 1. Node 0 in the graph corresponds to the course numbered 1 in Table 1, and the rest of the courses can be deduced in sequence.

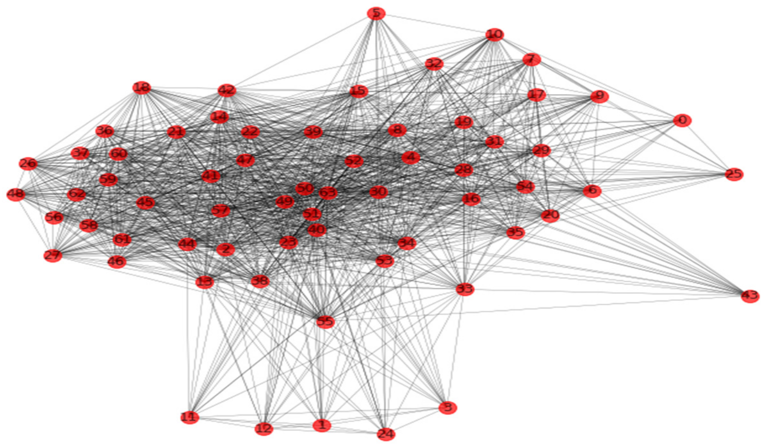

Fig. 1. Network of Electrical Engineering Curriculum System

3 Analysis of Network Statistical Characteristics

3.1 Degree centrality analysis

In network analysis, degree centrality directly characterizes the importance of nodes in the network[7]. The higher the degree value ki of a node, the more important it is in the network. The degree of a node is the sum of all weighted edges of that node. The calculation method of ki is shown as equation (4).

$$k_i = \sum_{j=1}^{64} a_{ij} \tag{4}$$

According to the course network graph in Figure 1, the calculated nodal distribution is shown in Table 2.

Define the degree centrality of node v_i as equation (5) shown:

$$C_D(v_i) = \frac{k_i}{N-1} \tag{5}$$

Where N is the number of nodes in the network. The degree centrality distribution of nodes is shown in Figure 2.

Table 2. Course Degree Distribution

Course No.	Degree	Course No.	Degree	Course No.	Degree	Course No.	Degree
1	18	17	40	33	32	49	39
2	17	18	28	34	37	50	62
3	51	19	39	35	59	51	60
4	17	20	38	36	40	52	62
5	54	21	40	37	39	53	57
6	20	22	50	38	39	54	59
7	37	23	50	39	45	55	44
8	34	24	61	40	54	56	47
9	58	25	16	41	62	57	39
10	32	26	18	42	49	58	50
11	38	27	39	43	45	59	39
12	17	28	39	44	22	60	39
13	17	29	41	45	54	61	39
14	51	30	36	46	39	62	39
15	48	31	63	47	39	63	39
16	53	32	39	48	49	64	63

From Table 2, it can be seen that the maximum degree value of nodes in the network is 63, and there are 19 nodes with degree values greater than 50, accounting for about 30% of the total number of nodes. From the perspective of the courses corresponding to the nodes, practical courses such as electrician technology internship, power grid course design, relay protection course design, and graduation design have a higher degree value, reflecting that these practical courses play a greater role in cultivating students' comprehensive abilities compared to knowledge transfer courses. Therefore, further strengthening the teaching management and quality control of these courses is necessary. Knowledge courses such as electromagnetic fields and electrical engineering also have a degree value of over 50, indicating that this course plays an important role in cultivating abilities and connecting the past with the future. Ideological and political courses such as ideological cultivation and legal foundations, college students' mental health, and the outline of modern Chinese history also have relatively high scores, indicating that these courses play an important role in cultivating students' professional norms, engineering and society, environment and sustainable development and other educational goals.

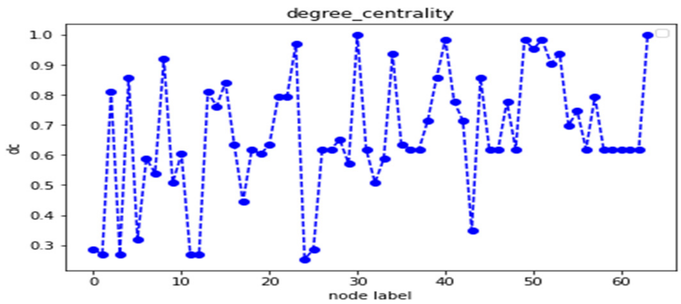

Fig. 2. Node Degree Centrality

Define P (k) as the proportion of nodes with a moderate degree of k in the entire network, and represent it as a histogram, as shown in Figure 3. It can be seen that nodes with a degree value of around 40 have the highest proportion in the network, and nodes with a degree value of around 40, a degree value of around 50, and a degree value of around 60 have similar proportions in the network. Since there is no single feature scale in the network, it can be considered as a scale free distribution[8].

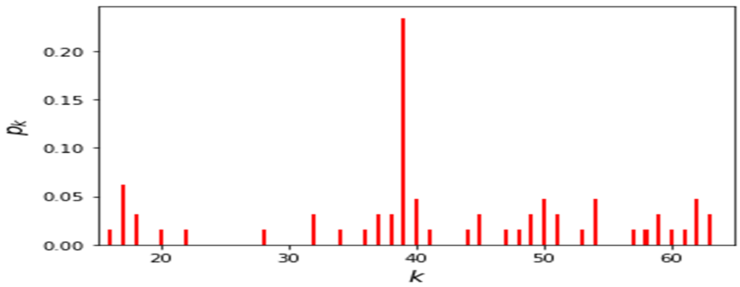

Fig. 3. Node Degree Distribution

3.2 Betweenness centrality analysis

In addition to degree centrality, the betweenness centrality of a network is also important. The betweenness number is used to measure the propagation ability of nodes in a network as intermediate nodes[9]. The betweenness number B_i of a node is defined as equation (6) shown:

$$B_i = \sum_{j \neq l \neq i} \frac{N_{j,l}(i)}{N_{j,l}} \quad (6)$$

Where $N_{j,l}$ is the number of shortest paths between node j and node l, while $N_{j,l}(i)$ is the number of shortest paths passing through node i between node j and node l. The betweenness centrality of nodes is defined as equation (7) shown:

$$C_B(v_i) = \frac{2B_i}{(N-1)(N-2)} \tag{7}$$

The calculation results of the betweenness centrality of the network in this article are shown in Figure 4.

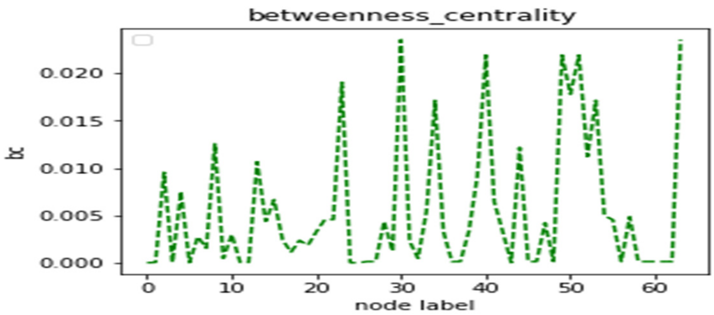

Fig. 4. Betweenness centrality of the network

The node with the highest betweenness centrality in the network is 30 nodes (corresponding to course number 31) - Electrical Technology Internship. Next are 40 nodes (power grid curriculum design), 49 nodes (power plant curriculum design), and 51 nodes (relay protection curriculum design). These courses all have high degree values and also play an important role in connecting different graduation ability requirements, cultivating students with strong comprehensive abilities.

3.3 K-core analysis

The kernel degree of a node indicates its depth within the kernel, and the maximum kernel degree corresponds to the central position in the network structure, revealing the hierarchical characteristics of the network. By using the k-shell decomposition method of the network[10], the k-core indicators corresponding to each node in the network can be obtained, and the k-core values of each node in the network in this paper can be calculated. The calculation results are shown in Figure 5.

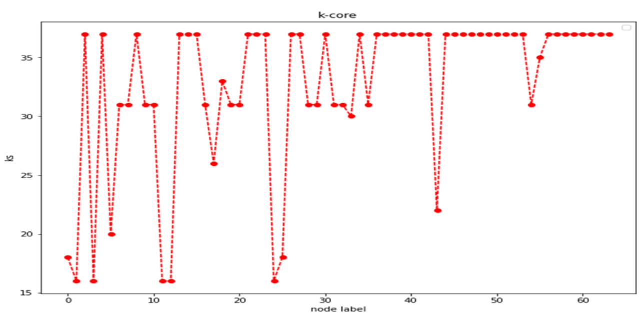

Fig. 5. K-core value distribution

Obviously, the network in this article can be decomposed into three shells, with the outermost layer consisting of nodes $k_s < 25$, the middle layer consisting of nodes $25 \leq k_s < 37$, and the innermost layer consisting of nodes $k_s \geq 37$. According to the k-core indicators of each node, the core nodes can be obtained by removing the nodes $k_s < 37$ as shown in Table 3.

Table 3. Core-course nodes

Course No.	Course Name	Course No.	Course Name
3	engineering drawing	45	Power Plant Electrical
5	Ideological cultivation and legal foundation	46	Transient analysis of power system
14	Circuit Theory	47	principles of Relay Protection
15	Electrical Testing Technology Experiment	48	High voltage technology
22	electromagnetic field	49	Automatic Control Technology of Power System
23	Electrical Engineering	50	Course Design for Power Plants
27	Analog Electronic Technology	51	Electrical Engineering CAD Technology
28	Digital Electronic Technology	52	Course Design of Relay Protection
31	Electrical Technology Internship	57	Electric Energy Measurement Technology
37	Steady state analysis of power system	58	Power Engineering Budget
38	Principles of Automatic Control	59	Lectures on New Power Technologies
39	Principles and Applications of Microcomputers	60	Large unit protection
40	Cognition Internship	61	Distribution network automation
41	Course Design for Power Grid	62	Automation of power system dispatch
42	power electronic technology	63	Power system planning
43	Principles and Applications of Microcontrollers	64	Graduation Design

4 Conclusion

This article takes the curriculum system for undergraduate students majoring in Electrical Engineering at changsha university of science and technology as an example, using the method of complex networks to explore the professional core courses with the greatest dissemination and influence in the course structure, providing an intuitive perspective for the quantitative evaluation of professional core courses and the exploration of the structural patterns inherent in the course system. The ideas and methods presented in this article are universal and suitable for scientific verification and course structure analysis of core courses in different majors. They can also be extended to structural and correlation analysis in other fields.

For ease of calculation, this article sets the same weight for each graduation requirement. If different weight values are assigned to different graduation ability requirements, which indicates a preference for the direction of cultivating graduates' abilities, diversified analysis results can be obtained.

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