Feature Analysis of Structural Mechanics Based on Association Rules Mining

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Abstract: The professional education courses in Civil Engineering include mathematics curriculum group, mechanics curriculum group and design curriculum group, the mechanics curriculum group serves as a link between the preceding and the following courses. In order to study the features of Structural Mechanics, this paper selects a total of 7 representative courses in the three curriculum groups. The final academic records of 249 students in three grades are used as research objects. By using the association rule algorithm—Apriori, this paper discusses the implementation process of data mining technology and clarifies the degree of relationship between the selected courses and Structural Mechanics. The analysis results can provide important references for the setting and structure adjustment of Structural Mechanics, targeting the key and difficult part of Structural Mechanics, teaching reform and academic learning monitoring and forecasting.

1. Introduction

Making a general survey of the major of Civil Engineering in China, the curriculum systems contain general education courses, basic disciplinary courses and specialized courses. Based on the characteristics of engineering education, the mathematics curriculum group in the basic disciplinary courses, the mechanics curriculum group and design curriculum group in the specialized courses are core courses in each stage of the undergraduate in Civil Engineering, and these courses are also the framework supporting the professional qualities and have the decisive significance to the achievement of training goals.

Structural Mechanics is a branch of solid mechanics. It mainly studies the response of the member structure under load and non-load factors: internal forces, reaction forces and displacements, as well as the reasonable compositional rules of structures, structure dynamic characteristics and structural stability. Structural Mechanics is an important basic course in Civil Engineering and related majors [1]. As shown in figure 1, it is not only the development and deepening of mathematics curriculum group (Advanced Mathematics, College Physics) and mechanics curriculum group (Material Mechanics, Theoretical Mechanics), but also the foundation of the design curriculum group (Reinforced Concrete Structure, Steel Structure, Timber Structure, Masonry Structure). Structural Mechanics occupies an important position in the entire Civil Engineering course system. And Structural Mechanics is also the professional courses in graduate entrance exam of Civil Engineering in China [3].

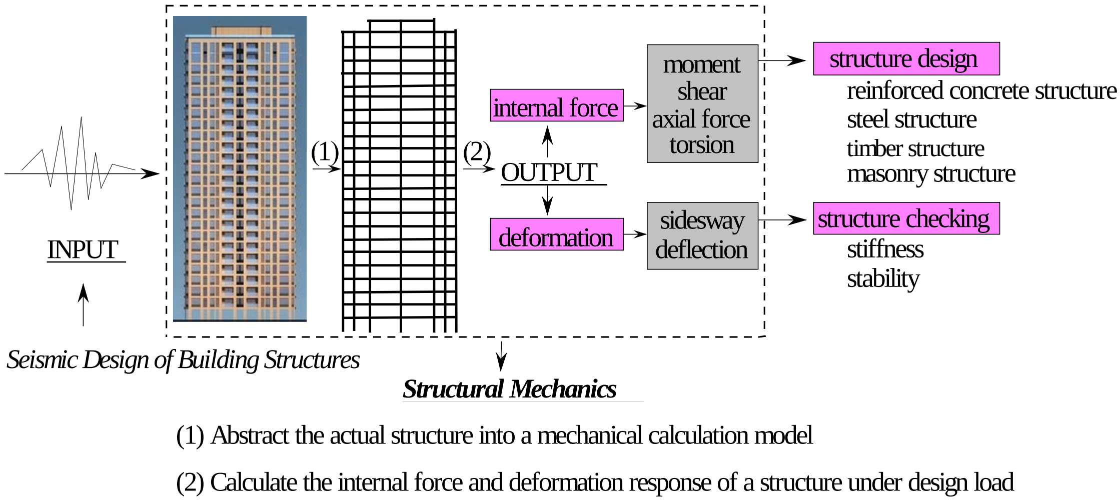

Figure 1. Status and role of the Structural Mechanics [2]

Six courses are selected in this paper: Advanced Mathematics (volume 1, “AM1” for short), Advanced Mathematics (volume 2, “AM2” for short) and Linear Algebra (“LA” for short) from the mathematics curriculum group, Theoretical Mechanics (“TM” for short) and Material Mechanics (“MM” for short) from the mechanics curriculum group, the Design Theory for Concrete Structure (“CS” for short) from the design curriculum group. The correlation between the above 6 courses and Structural Mechanics (“SM” for short) are studied in this paper. There are three principles for selecting courses:

Firstly, the representativeness. The selected 6 courses are all core courses of the curriculum system and are also the postgraduate entrance examination courses or the postgraduate re-examination courses.

Secondly, the course coverage. A certain sequence existed in all the 7 courses, and the 7 courses cover the freshman to junior year. The investigation of the correlation between the selected courses and SM can reflect students' learning behavior habits during college and can be used to guide the setting of SM and the monitor and predict of academic learning condition.

Thirdly, the correlation. The selected courses should have the basic premise of correlation analysis, so that the conclusion of correlation analysis is instructive. In Civil Engineering, the mathematics courses are the basis of the mechanics courses, and the mechanics courses directly guide the design courses.

This paper selects 7 courses in Civil Engineering, taking the academic performance of 249 students in three grades as the research object, and adopting the association rule mining algorithm—Apriori to explore the implementation process of data mining technology in course analysis, and to explore the depth of the relationship between each core curriculum and SM. The analysis results can provide important references for the setting and structure adjustment of SM, targeting the key and difficult part of SM, teaching reform and academic learning monitoring and forecasting.

2. Research Method

Course correlation analysis is used to describe the degree of relevance between courses. At present, the methods adopted by the course correlation analysis research are mostly based on data mining technology, mainly including correlation analysis, typical correlation analysis and association rule analysis [4]. Among them, the association rule analysis method, especially represented by the Apriori algorithm, is the most widely used. Association rule mining is to find frequent patterns, associations, correlations or causality among item sets or object sets in transaction data, relational data, or other information carriers [5]. Association rule mining is a simple and practical analysis technique. It discovers the associations or correlations existing in a large number of data sets, and thus describes the rules and patterns of certain attributes.

2.1 Apriori Algorithm

Let D be set of transaction called database, $D=\{t_1,t_2,\ldots,t_k,\ldots,t_n\}$, $t_k=\{i_1,i_2,\ldots,i_m,\ldots,i_p\}$, t_k (k=1,2,…,n) is called transaction, i_m (m=1,2,…,p) is called item. Let I be set of all the items in D, $I=\{i_1,i_2,\ldots,i_m\}$, the subset of I is called itemset. If the size of a subset X is k, the subset X is called k-itemset. The number of transactions in which X appears is called the support number of X, denoted as σ_x. The support of X is:

$$\text{support}\left(X\right)=\frac{\sigma_x}{|D|}\times 100\% \tag{1}$$

Where |D| is the total number of transactions.

X and Y are itemset, and if $X\cap Y\neq\emptyset$, $X\rightarrow Y$ is called an association rule. X and Y are called the premise and conclusion of the association rule respectively. The support of association rule $X\rightarrow Y$ is denoted as support $(X\rightarrow Y)$:

$$\text{support}\ (X\rightarrow Y)=\text{support}\ (X\cup Y) \tag{2}$$

The confidence of association rule $X\rightarrow Y$ is denoted as confidence $(X\rightarrow Y)$:

$$\text{confidence}\left(X\rightarrow Y\right)=\frac{\text{support}\left(X\cup Y\right)}{\text{support}\left(X\right)}\times 100\% \tag{3}$$

Support and confidence can directly describe the association rule. Support describes the probability of the union of X and Y appears in all transactions. Confidence is a measure of the accuracy of association rule, and support is a measure of the importance of association rule. Support indicates how representative the association rule is in all transactions. Obviously, the larger the support, the more important the association rule is. Although some association rules have a high confidence, support is low, which indicates that the chance of the association rule to be practical is very small and therefore not important [5]. In view of the limited number of transactions, support of multi-set is low, and the fact that the 2-itemset relationship between courses is the most logical and instructive, this paper focused on the correlation of 2-itemset of courses.

2.2 Data cleaning & management

This paper will analysis the course correlation among 7 selected courses (AM1, AM2, LA, TM, MM, SM, CS) based on the academic performance of students, filter out the no-show, delay, exemption, violations of discipline, etc., and record the 7 courses of 249 students in 2014-2016 as transactions D, which contains 249 transactions, each transaction t_k is a 7-itemset.

Table 1. Discrete method of students' academic performance

Researcher (Year)	Number of Discrete Grades	Discrete Standard
Cui Xuewen (2011)[6]	2	[90,100], [0,90)
Yao Shuangliang (2012)[7]	3	[80,100], [60,80), [0,60)
Wang Hua, Liu Ping (2015)[8]	3	[80,100], [60,80), [0,60)
Zhan Feng, Liu Boyan (2018)[9]	4	[80,100], [70,80), [60,70), [0,60)
Wu Feiqing et. al (2019)[10]	4	[85,100], [70,85), [60,70), [0,60)
Wu Xiaodong, Zeng Yuzhu (2019)[11]	5	[90,100], [80,90), [70,80), [60,70), [0,60)

Table 1 shows the methods used by other researchers to discretize student performance before using Apriori algorithm for correlation analysis. All the researchers chose the integrated scores as discrete objects, and adopted the fix-width method to grade, which means each grade has the fix threshold values.

Considering the integrated score of each course is composed of process assessment (homework, attendance, classroom performance, etc.) and final assessment (final exam) in a certain proportion. Jiang Hui et al. [12] found that there was no significant linear correlation between the final assessment results and the process assessment results of most courses. In other words, the integrated score cannot directly reflect the level of students' mastery of curriculum knowledge. It is easy to understand, on the one hand, the process assessment is aimed at process management, focusing on students' attitudes and investment in learning, while sometimes the investment and production are disproportionate, especially when students purposely cater to the process assessment but not truly throwing themselves into the study; on the other hand, in order to make the distribution of integrated scores more reasonable, teachers may artificially adjust the process assessment results of some students, especially for students with learning difficulties, the process assessment results will significantly improve the integrated score. In order to visually measure the level of students' knowledge and ability, this paper chooses the score of final assessment (final exam) as the discrete object.

In addition, different courses and different grades have great differences in the difficulty of final test, and the teachers have different habit and standard during grading the papers. All the factors mentioned above often results in huge differences in the average and variance of the scores among courses, and even in some courses the scores do not meet the normal distribution. Therefore, it should not simply consider the scores as the abilities. In this paper, fix-frequency method was adopted. For the same course, it takes the quartiles of the scores of the final assessment (final exam) of all students in the same class. The top 25% is "excellent", the upper 25% is "good", the lower 25% is "medium" and the last 25% is "poor". Represented by 1, 2, 3, 4 respectively.

Finally, for the convenience of description, the 7 selected courses (AM1, AM2, LA, TM, MM, SM, CS) are denoted by A, B, C, D, E, F and G respectively. For example, if a student's score of material mechanics ranks in the top 25% of the class, after data cleaning and management, the level of the students' mastery of material mechanics is represented as E1.

3. Results of Data Mining

Any two courses I and J, the course I starts earlier than course J. As shown in figure 2(a), there are 16 types of students' scores between the two courses. For instance, I2→J4 indicates that the score in course I is "good", but "poor" in course J. The relationship In→Jn shown in figure 2(b) indicates the continuity or inertia of the results between two courses, which means that the students achieved the same grade in the two courses. The relationship shown in figure 2(c) (I1→J4 or I4→J1) indicates the reversal of the grades between courses, which means that the students achieved completely opposite grades in the two courses. Theoretically, the closer the two courses are, the stronger the continuity of knowledge, the higher the relevance of the course, the stronger the inertia of the test score of the same student, the lower the possibility of reversal, and vice versa. In order to measure the inertia and reversal of students' course performance, define the inertia index and reversal index:

$$K_{in} = \sum_{i=1}^{4} \text{support}\left(I_i \rightarrow J_i\right) \tag{4}$$

$$K_{re} = \text{support}\left(I_1 \rightarrow J_4\right) + \text{support}\left(I_4 \rightarrow J_1\right) \tag{5}$$

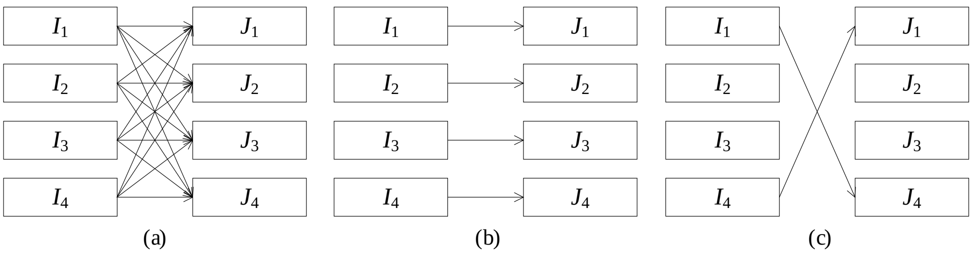

Figure 2. Correlativity between courses

Table 2. Results of relevance analysis

Rules	Support (%)	confidence (%)	Rules	Support (%)	confidence (%)	Rules	Support (%)	confidence (%)
A1→F1	11.2	46.7	B1→F1	10.4	43.3	C1→F1	10.8	45.0
A2→F2	7.2	31.0	B2→F2	6.4	26.7	C2→F2	7.2	29.0
A3→F3	7.2	27.7	B3→F3	7.2	27.7	C3→F3	9.2	36.5
A4→F4	10.4	39.4	B4→F4	11.2	43.8	C4→F4	11.2	43.8
A1→F4	2.4	10.0	B1→F4	2	8.3	C1→F4	2.4	10.0
A4→F1	2.8	10.6	B4→F1	4	15.6	C4→F1	3.2	12.5
D1→F1	12	48.4	E1→F1	13.7	55.7	F1→G1	13.7	54.0
D2→F2	8	33.9	E2→F2	6.4	26.7	F2→G2	8	33.3
D3→F3	5.6	22.2	E3→F3	8	31.3	F3→G3	9.6	38.1
D4→F4	12.9	49.2	E4→F4	15.7	60.9	F4→G4	16.5	65.1
D1→F4	0.4	1.6	E1→F4	0.4	1.6	F1→G4	0.4	1.6
D4→F1	2	7.7	E4→F1	0.4	1.6	F4→G1	0.8	3.2

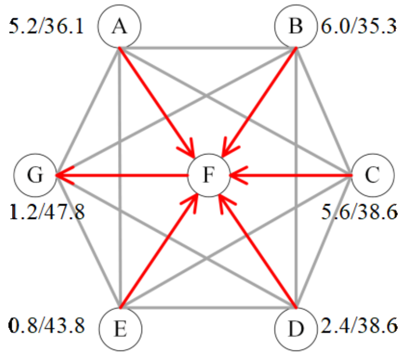

Figure 3. Inertia index K_{re} and reversal index K_{in} among courses (%)

Table 2 shows the results of the association analysis between the selected 6 core courses and SM. Figure 3 shows the inertia index and reversal index between the 7 core courses.

4. Correlation Analysis

According to the talent training program, a certain sequence existed in the selected 7 courses, and the 7 courses cover the freshman to junior year. From the results of correlation analysis in Table 2 and the inversion index and inertial index in figure 3, the following phenomena and rules can be found:

(1) There is a significant grade solidification between the selected 6 core courses and SM, proving the close correlation among the mathematics course group, the mechanics course group and the design course group of Civil Engineering. The grade solidification phenomenon is especially present in the groups of superior students and poor students. The confidence of "I1→J1" and "I4→J4" among the courses are almost all above 40%, where $conf_{max}$ = conf (F4→G4) = 65.1%, $conf_{min}$ = conf (A4→F4) = 39.4%. Although the support and confidence of "I2→J2" and "I3→J3" are less than "I1→J1" and "I4→J4", if the "good" and "medium" are combined, the four grades of "excellent, good, medium and poor" will be changed to three grades of "excellent, medium and poor". After analysis by the Apriori algorithm, the results are shown in Table 3. The support and confidence of the "medium" grade students in the correlation analysis of each course are significantly improved compared to the "good" and "medium" grades in Table 2, indicating that students with moderate grades have very high mobility in the two levels of "good" and "medium", reflecting the learning effects of these students have the highest sensitivity on the course characteristics, teaching methods and even teachers' personal charisma.

Table 3. Results of relevance analysis (combined "good" and "medium")

Rules	Support (%)	Confidence (%)	Rules	Support (%)	Confidence (%)
$A_{med}\rightarrow F_{med}$	25.7	52.0	$D_{med}\rightarrow F_{med}$	25.7	52.5
$B_{med}\rightarrow F_{med}$	27.3	54.4	$E_{med}\rightarrow F_{med}$	29.3	58.9
$C_{med}\rightarrow F_{med}$	27.3	54.4	$F_{med}\rightarrow G_{med}$	30.1	61.0

(2) The correlation among the mechanics curriculum group and the correlation between SM and CS were significantly higher than that between the mathematics courses and SM. As shown in Table 2, although the overall grade solidification between the 7 core courses is obvious (the confidence of "I1→J1" or "I4→J4" is high, the support and confidence of "I1→J4" or "I4→J1" is very low), the grade solidification trend is still different among internal courses (from the same curriculum group) and external courses (from different curriculum groups). Figure 3 shows the reversal index (K_{re}) and inertia index (K_{in}) between the selected 6 core courses and SM, and figure 4 shows the sequence diagram of K_{re} and K_{in}. The lower the reversal index and the higher the inertia index, the stronger the relevance between the courses. As shown in figure 4, the correlation between the three major mechanics courses in Civil Engineering (D→F, E→F) and the correlation between SM and CS (F→G) show significant strong correlation characteristics. Among all the course correlation, the correlation between MM and SM (E→F), SM and CS (F→G) is the strongest. At the same time, the influence of mathematics courses on SM (A→F, B→F, C→F) is significantly lower than that of mechanics courses on SM (D→F, E→F), which adequately indicated the unique characteristics of SM. This phenomenon can be explained as the importance of the solution of internal force and deformation of the frame structure in SM to the design course CS. However, the solution process does not require in-depth mathematical knowledge (actually, the computational difficulty of statically determinate structure and statically indeterminate structure is limited to basic arithmetic).

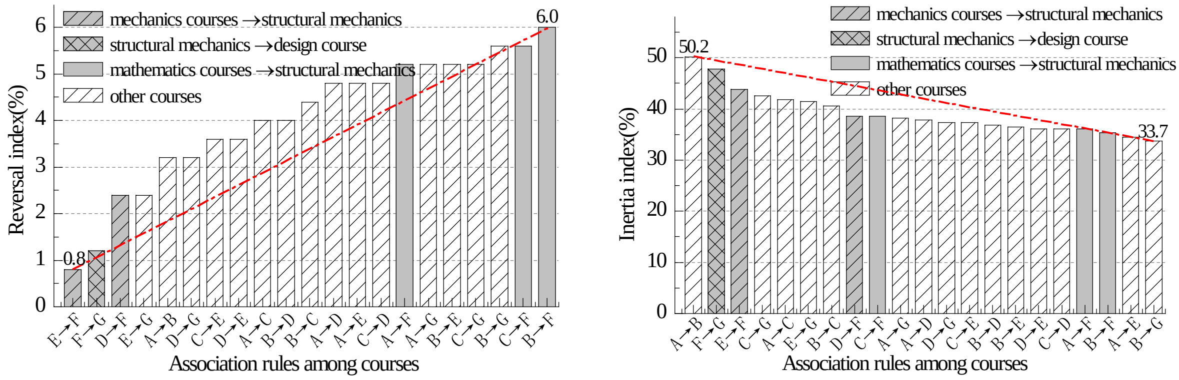

Figure 4. Sequence diagram of K_{re} and K_{in} among courses

(3) The key course of the mechanics curriculum group is MM. As show in Table 2, in the mechanics curriculum group, MM→SM has a higher confidence in each grade ($I_n\rightarrow J_n$) than TM→MM and TM→SM. In addition, as show in figure 3 and 4, according to the K_{re} and K_{in}, the correlation between MM→SM is the highest. Finally, from the content of the course [13, 14], MM presents the theory and supports the application of essential mechanics of materials principles. SM takes the frame structure as the object and further expands the solution of internal force (bending moment, shear, axial force) and deformation. Therefore, for MM to SM, the knowledge system in the latter course is the inheritance and extension of that in the former course.

5. Conclusion

This paper selects 7 representative courses in the mathematics curriculum group, mechanics curriculum group, and design curriculum group in Civil Engineering, taking the final exam scores of

249 students in three grades as the research object. The association rule mining algorithm — Apriori is used to further explore the data mining technology in higher education research. This paper proposed the concept of inertia and reversal among courses, and constructed the inertia index and reversal index. The relationship among courses was explored by combining the parameter of support and confidence. It is found that:

(1) there is a significant grade solidification between the selected 6 core courses and SM;

(2) the correlation among the mechanics curriculum group and the correlation between Structural Mechanics and Design Theory for Concrete Structure were significantly higher than that between the mathematics courses and Structural Mechanics;

(3) the key course of the mechanics curriculum group is Material Mechanics.

The analysis results can provide important references for the setting and structure adjustment of Structural Mechanics, targeting the key and difficult part of Structural Mechanics, teaching reform and academic learning monitoring and forecasting.

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