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Abstract. *This research aimed to explore the conceptual structure of chemical equilibrium in upper-secondary school students using factor analysis. Research on chemistry education has shown that chemical equilibrium is an important but difficult-to-understand topic. Exploring the conceptual structure of chemical equilibrium among students will help chemistry researchers and educators to conduct more targeted teaching practices. Based on a survey of chemistry research and teaching practice experts, a high-quality concept pool composed of 24 relevant concepts was developed. Next, a survey involving a total of over 700 twelfth-grade students from five upper-secondary schools was conducted, and a factor analysis was utilized to determine the conceptual structure. The results showed that a three-factor model and a five-factor model with 15 relevant concepts were all accepted as the conceptual structure for students. The new form of conceptual structure in this research helps understand the features and categories in students' latent organization of concepts. Also, it may be revealed that factor analysis can be utilized as an approach to exploring students' conceptual structure.*

Keywords: *chemical equilibrium, chemistry education, conceptual structure, factor analysis*

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THE CONCEPTUAL STRUCTURE OF CHEMICAL EQUILIBRIUM IN UPPER-SECONDARY SCHOOL STUDENTS: EVIDENCE FROM FACTOR ANALYSIS

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Introduction

Concepts and their structure are fundamental and significant issues in cognitive psychology. As influential factors, they play critical roles in cognitive processes. It is thus indispensable to explore and understand the conceptual structures that students hold of science concepts (Taber, 2003).

Different techniques have been developed to determine and represent the different forms of an individual's conceptual structure (Jonassen, et al., 1993). Similarity rating (or relatedness rating) is one of the bases of these techniques, which requires individual to rate the degree of similarity (or the degree of relatedness) between pairs of concepts (Goldsmith, et al., 1991; Giamellaro, 2014; Neiles, et al., 2016). As an example, word association is a short-timed test to identify the conceptual structure individual has of certain concepts (Derman & Eilks, 2016; Geeslin, & Shavelson, 1975; Nakiboglu, 2008; Yener, et al., 2018). Additionally, using the matrix of proximity values, multidimensional scaling (MDS) and the Pathfinder network algorithm are common methods of exploring global and local information regarding the conceptual structures of individuals and groups (Giamellaro, 2014; Goldsmith, et al., 1991; Neiles, et al., 2016). The large sample of rating data can also be processed by other data analysis methods, such as factor analysis. However, little research has reported on the use of factor analysis to determine the latent structure of science concepts in students.

Research has consistently shown that chemical equilibrium has been considered as an important but difficult chemistry topic for students to learn (Bergquist & Heikkinen, 1990; Finley, et al., 1982). To understand the learning process and outcome for this topic, and to select suitable teaching methods, researchers have conducted various research studies on students' understanding of chemical equilibrium. Students' misconceptions (Akkus, et al., 2011; Barke, et al., 2009; Hackling & Garnett, 1985; Karpudewan, et al., 2015; Özmen, 2008; Quílez, 2004; Quílez-Pardo & Solaz-Portolés, 1995), mental models (Chiu, et al., 2002), and conceptual structures (Gorodetsky &

Hoz, 1985; Gussarsky & Gorodetsky, 1988, 1990; Wilson, 1994, 1996) for chemical equilibrium have been identified and analyzed. A deeper understanding of students' thinking regarding chemical equilibrium can be utilized to develop more effective teaching methods to improve the classroom teaching (Akkuş, et al., 2003; Maia & Justi, 2009; Ollino, et al., 2018; van Driel, et al., 1998). Conducting research involving factor analysis would be beneficial to fully understand the organization of concepts and to promote the development of teaching methods.

Conceptual Structure and Factor Analysis

Generally speaking, different theoretical perspectives have provided a diverse understanding of the conceptual structure regarding the relation between concepts. This has made the conceptual structure of a polysemous term with multiple meanings. In the classical view, concepts can be divided into different categories because those in the same category have similar attributes or prototypes (Medin, 1989; Moss, et al., 2007; Rosch, 2002). The associated set of attributes or the prototypes belonging to concepts can be considered as conceptual structures. Cognitive psychologists have concerned about how the attributes or the prototypes construct the concepts.

On the other hand, the conceptual structure can be utilized to denote the relation between concepts in declarative memory, such as a hierarchical organization of concepts, a propositional network, or other forms. In the first form of conceptual structure, a significant concept and its relevant concepts are hierarchically organized to form the categories and subcategories (Zimbardo, et al., 2017). In the second form of conceptual structure, the combinations of concepts produce the propositional statements and semantic network. The concept map is a typical structural representation of the propositional network in the domain knowledge (Novak & Gowin, 1984; Soika & Reiska, 2014). Moreover, the spreading activation theory has proposed that relevant concepts are distributed around the core concepts in the conceptual structure, basing on the degree of relatedness and the frequency of use (Collins & Loftus, 1975). Because conceptual structure represents how individual organize and understand the concepts in own mind, researchers have referred to it as a cognitive structure, a knowledge structure, or a structural knowledge (Geeslin & Shavelson, 1975; Goldsmith, et al., 1991; Jonassen, et al., 1993; Nakiboglu, 2008). Reviewing students' conceptual structures of science topics is essential in science learning and education (Taber, 2003). Classification and composition are advised as the fundamental semantic relations between science concepts in science texts (Unsworth, 2001).

Factor analysis shows the latent interrelationships (known as correlations) between the factors and variables (Hair, et al., 2010; Schinka & Velicer, 2003). The variables are categorized into different factors basing on their high correlations, sharing the common meaning of the belonging factor. The model composed of the factors and their variables reveals how the individuals consider a certain topic at the group-level. Factor analysis includes exploratory factor analysis (EFA) and confirmatory factor analysis (CFA). As a data-driven analysis, EFA extracts latent common factors from the variables, reduces the number of variables, and obtains a simple model that represents the relation between the factors and variables. In contrast, CFA is a theory-driven analysis, which tests, compares, and modifies the hypothesized models from EFA or theoretical assumptions (Hair, et al., 2010; Harrington, 2009).

As a famous example, factor analysis has been utilized to discover personality traits from individuals' rating of trait terms that defined the personality components in personality psychology research. Cattell's Sixteen Personality Factors and Five-Factor Model have been all extracted by using factor analysis (Dumont, 2010). Factor analysis is an essential means of exploring the variety of personality structures (Cawley, et al., 2000; Kaufman, et al., 2019), and is widely utilized in the psychometric evaluation of measures, construct validation, and for other purposes (Schinka & Velicer, 2003).

The new form of conceptual structure for science concepts was expected to be based on the high correlations between the categories of concepts (known as factors) and their relevant concepts and to represent a new different facet of latent organization of the science concepts from students.

Students' Conceptual Structure of Chemical Equilibrium

To understand how the concepts related to chemical equilibrium are organized and stored in the memory, researchers have conducted research studies on the conceptual structure of chemical equilibrium in students (Gorodetsky & Hoz, 1985; Gussarsky & Gorodetsky, 1988, 1990; Wilson, 1994, 1996). In the research conducted by Wilson (1994), upper-secondary school chemistry students completed a concept mapping task individually, then the concept maps were transformed into proximity matrices and analyzed by Pathfinder. The results indicated that



different achievement groups had differences in important specific conceptual relations and hierarchical organization. Using a similar research methodology for upper-secondary school chemistry students, Wilson (1996) found a significant relation between academic achievement in chemistry and the characteristics of the conceptual structure as represented in a concept map.

Besides, Gussarsky and Gorodetsky (1988) utilized constrained word associations to find the categories of concepts in the conceptual structures of chemical equilibrium from upper-secondary school students with different levels in chemistry. In their other research (Gussarsky & Gorodetsky, 1990), free word associations were utilized to determine the respective conceptual structure of 'equilibrium' and 'chemical equilibrium' in upper-secondary school students. The results indicated that the distribution of concepts in these two conceptual structures could explain the misconceptions caused by the semantic similarity of these concepts. Furthermore, Gorodetsky and Hoz (1985) employed latent partition analysis (LPA) to analyze students' free-sorted concept results and thus to reveal the 'group cognitive structure' of freshman engineering students. The latent categories of concepts from different achievement groups were also extracted and compared.

It is worth noting that previous researchers have individually found and listed concepts from chemistry curriculum materials (Gorodetsky & Hoz, 1985; Gussarsky & Gorodetsky, 1988; Wilson, 1994, 1996). Their concept pools were thus easily influenced by personal subjective judgment. Besides, these concept pools included the concepts in respect of some specific reactants, phase change, or salt solution. There were few concepts regarding the shift of the chemical equilibrium state. Because the number and scope of concepts affect the organization and quality of a conceptual structure, it is necessary to provide a high-quality concept pool when researching conceptual structure.

The analytical techniques utilized in previous research studies have represented different forms of conceptual structure of chemical equilibrium in students. Factor analysis is a means to explore and provide a new form of conceptual structure, though it has not been reported on the topic of chemical equilibrium. Moreover, the number of latent factors, as well as the actual relation between concepts, was not yet clear and expected to be answered.

Research Questions

In this research, we attempted to utilize factor analysis to expand the diversity of conceptual structure. The specific research questions that guided this research were as follows:

- (1) What is the concept pool of chemical equilibrium acquired by university chemistry researchers and upper-secondary school chemistry teachers?
- (2) What is the conceptual structure of chemical equilibrium held by Chinese upper-secondary school students, as shown by factor analysis?

Research Methodology

General Background

This research was a quantitative-oriented survey, which involved a large number of chemistry research and teaching practice experts, and upper-secondary school students in Guangzhou, China during the 2019-2020 academic year. In the first part of this research, the concept pool of chemical equilibrium was acquired through a survey questionnaire to university chemistry researchers and upper-secondary school chemistry teachers. This ensured that our list of relevant concepts made theoretical and practical sense. Second, the conceptual structure for students was determined through EFA and CFA of survey data from students.

Participants

This research utilized three groups of participants, all from Guangzhou, the capital of Guangdong province in China. Their demographic characteristics are listed in Table 1.



Table 1*Demographic Characteristics of Participants*

Group	N	Age		Teaching experience year		Gender	
		M	SD	M	SD	Male	Female
Group 1 Upper-secondary school chemistry teachers	204	39.60	6.68	16.56	7.23	71	133
Group 2 University chemistry researchers	10	45.20	6.89	17.40	7.96	7	3
Group 3 Upper-secondary school students	602	16.74	0.49	-	-	306	300

The concept pool must have a wide scope of concepts, which are on the subject of the origin and change of chemical equilibrium. To make an appropriate concept pool of chemical equilibrium, 224 upper-secondary school chemistry teachers and 25 university chemistry researchers were invited to participate in the concept pool surveys, respectively.

In the survey of upper-secondary school chemistry teachers (Group 1), 204 teachers' questionnaires were valid (recovery rate: 91.1%). The participants were in a unique position to effectively judge the relatedness of concepts related to chemical equilibrium from the perspective of upper-secondary school chemistry teaching practice.

In the survey of university chemistry researchers (Group 2), 10 researchers accomplished the survey (recovery rate: 40.0%), comprising seven professors and three associate professors. Half had published research studies regarding inorganic chemistry and others were experts in physical chemistry. This group was in an appropriate position to give reasonable suggestions in respect of the concept pool of chemical equilibrium from the perspective of chemistry research.

After the concept pool was produced, a total of 705 twelfth-grade students from five upper-secondary schools were invited to participate in the conceptual structure survey. The valid sample comprised 602 students (Group 3; recovery rate: 85.4%). There were 313 students from two ordinary upper-secondary schools studying chemistry at a basic level, and 289 students from three key upper-secondary schools having a higher level of chemistry. All students had studied chemical equilibrium in a chemistry elective module before participating in the survey. The sample of upper-secondary school students was randomly split into two sub-samples (Group 3a and 3b) to conduct EFA and CFA on different rating data sets.

Participants were invited via the writers and informed of the intent of this research. They agreed to accomplish the survey.

Instrument and Procedures

The research instrument was a Chinese-language questionnaire about the concept pool of chemical equilibrium. The questionnaire development had two stages. In the first stage, an initial concept pool of chemical equilibrium was established. First, the upper-secondary school chemistry curriculum materials in China were analyzed to determine the concepts related to chemical equilibrium. The curriculum materials comprised the chemistry curriculum standards of China (MOE, 2003, 2018), chemistry textbooks of a compulsory module and an elective module (Song, 2007a, 2007b; Wang, 2007; Wang, et al., 2007; Wang, 2014a, 2014b), and a general college entrance examination outline (National Education Examinations Authority, 2018). According to the content of the concepts in chemistry, twenty-six concepts involving the concept learning of chemical equilibrium in chemistry module were selected. The concepts about specific reactants, acid-base equilibrium, solubility products, and phase equilibrium were not included in the result. Next, three upper-secondary school senior teachers and an associate professor in physical chemistry inspected the result and recommended five concepts. Thirty-one concepts were selected as an initial concept pool. The first draft of the questionnaire consisted of these concepts as items and utilized a 7-point Likert scale to rate each item's degree of relatedness to the concept 'chemical equilibrium', in order to select the relevant concepts. The scale had seven labels: the most unrelated, more unrelated, unrelated, not sure, related, more related, and the most related, which were assigned from 1 to 7 points respectively.

In the second stage, upper-secondary school chemistry teachers and university chemistry researchers (Groups 1 and 2) received a survey invitation E-mail sent by the writers and accomplished the survey online. They utilized



the first draft of the questionnaire to provide the rating regarding the degree of relatedness. When the average scores of both groups in an item were greater than 5, the concept corresponding to that item was accepted as a relevant concept in the formal concept pool. As is shown in Table 2, 24 concepts were accepted and utilized as items in the formal questionnaire. Using the same 7-point Likert scale as before, the formal questionnaire required participants to rate the degree of relatedness between each item and the concept 'chemical equilibrium'. The relatedness rating represented the participant's judgement of the semantic distances between the relevant concepts and the concept 'chemical equilibrium' in cognitive structure. Five upper-secondary school students randomly selected participated in a small interview. Their statements indicated that they could distinguish the meaning of concepts utilized as items.

Table 2
The Concept Pool of Chemical Equilibrium

Category	Number	Concepts
Quantitative representation	5	Chemical equilibrium constant, Limitation of chemical reaction, Establishment of the equilibrium state, Degree of conversion at equilibrium, Reaction quotient
Shift of state	5	Le Chatelier's Principle, Shift of equilibrium state, Direction of the shift in chemical equilibrium, Position of equilibrium moved to the right, Position of equilibrium moved to the left
Feature of equilibrium	4	Feature of chemical equilibrium, Dynamic equilibrium, Reversible process, Reversibility
Reversible reaction	3	Reversible reaction, Forward reaction, Reverse reaction
Reaction rate	3	Chemical reaction rate, Rate of the forward reaction, Rate of the reverse reaction
Condition	4	Condition, Temperature, Concentration, Pressure

After formal questionnaire development, a survey involving upper-secondary school students (Groups 3) was conducted with a paper and pen. They took 15 minutes to complete the questionnaire in a chemistry class.

Data Analysis

Data analysis had two stages. First, descriptive statistics of SPSS 23.0 were utilized to calculate the average score of items, based on the rating data from three groups of participants. Data checking found that the participants utilized 1 through 4 points in the rating, meaning they have utilized the full scale. Average scores of items greater than 5, which were from upper-secondary school chemistry teachers and university chemistry researchers (Groups 1 and 2), were utilized to decide the corresponding concept accepted in the formal concept pool of chemical equilibrium.

Secondly, factor analysis was conducted on the rating data obtained from the upper-secondary school student survey, to determine the conceptual structure of chemical equilibrium. EFA was conducted on the rating data of Group 3a. Principal axis factoring and Promax rotation method in SPSS 23.0 were utilized to extract the initial factors and their model. To test and compare the models provided by EFA or theoretical assumption, CFA was conducted on the rating data of Group 3b. The Robust Maximum Likelihood Estimation (MLR) of Mplus 7 was utilized to estimate the model parameters.

Research Results

The Concept Pool of Chemical Equilibrium

Table 3 shows that the average scores given to five items by both upper-secondary school chemistry teachers and university chemistry researchers are less than 5: 'endothermic reaction', 'exothermic reaction', 'activation energy', 'catalyst' and 'motionless'. Upper-secondary school teachers' average score of the item 'initial concentration' is also less than 5. These six concepts were thus rejected as relevant concepts in the formal concept pool of chemical equilibrium.

On the other hand, the average score of the item 'equilibrium concentration' is similar to that of the item 'con-



centration'. Because 'equilibrium concentration' is a subordinate concept of 'concentration' and upper-secondary school students easily confuse the two included in the same concept pool. After careful deliberation by the writers, the concept 'equilibrium concentration' was not accepted as part of the concept pool.

Table 3*The Average Scores of Items in the Survey*

Item	Upper-secondary teachers		University researchers		Upper-secondary students	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Dynamic equilibrium	6.69	0.66	6.70	0.67	6.32	0.98
Chemical equilibrium constant	6.64	0.70	6.90	0.32	6.45	0.79
Reversible reaction	6.48	0.80	5.60	0.84	6.13	0.96
Limitation of chemical reaction	6.44	0.86	6.20	0.92	5.85	1.12
Le Chatelier's Principle	6.43	0.97	6.60	0.97	6.42	0.91
Shift of equilibrium state	6.40	0.86	6.70	0.67	6.46	0.80
Reversibility	6.40	0.89	6.40	0.70	5.97	1.00
Degree of conversion at equilibrium	6.30	0.90	6.30	1.25	6.13	0.93
Feature of chemical equilibrium	6.27	0.94	6.20	1.14	6.16	0.99
Direction of the shift in chemical equilibrium	6.16	1.02	6.20	0.79	6.32	0.84
Establishment of the equilibrium state	6.14	1.16	6.00	0.94	5.91	1.11
Concentration	6.08	1.07	6.10	0.88	5.88	1.06
Equilibrium concentration	6.06	1.07	6.10	1.29	-	-
Reversible process	6.03	1.16	5.40	1.07	5.89	1.07
Reaction quotient	6.03	1.18	6.10	1.10	5.46	1.22
Reverse reaction	6.01	1.11	5.90	0.74	5.89	1.08
Position of equilibrium moved to the right	5.96	1.14	6.10	0.88	6.00	1.03
Temperature	5.96	1.12	6.40	0.70	5.65	1.03
Position of equilibrium moved to the left	5.86	1.17	5.70	1.06	6.01	0.98
Condition	5.65	1.48	6.00	0.94	5.83	1.09
Forward reaction	5.53	1.20	5.40	1.17	5.72	1.10
Pressure	5.45	1.23	5.50	1.08	5.79	1.08
Chemical reaction rate	5.40	1.51	5.20	1.69	6.12	0.98
Rate of the reverse reaction	5.37	1.41	5.20	0.92	5.77	1.03
Rate of the forward reaction	5.19	1.43	5.10	1.52	5.71	1.04
Endothermic reaction	4.98	1.64	4.90	1.60	-	-
Exothermic reaction	4.76	1.61	4.50	1.78	-	-
Initial concentration	4.68	1.69	5.00	1.25	-	-
Activation energy	4.44	1.74	4.50	1.72	-	-
Catalyst	3.97	1.81	4.70	1.89	-	-
Motionless	3.77	2.01	3.10	1.10	-	-

In the end, twenty-four relevant concepts were accepted as a formal concept pool of chemical equilibrium. Based on the classification and composition relation between those concepts in chemistry, the concept pool was divided into six categories by the suggestions of chemistry research and teaching practice experts. The names and components of the categories are shown in Table 2. This six-category model was considered as a scientific model



regarding the domain knowledge of chemical equilibrium. Especially, the concept 'feature of chemical equilibrium' summarized by Chinese upper-secondary school chemistry teachers means some main features of chemical equilibrium. This concept is widely utilized in Chinese upper-secondary school chemistry teaching practice so that it is familiar to students. Therefore, it should be admitted to the concept pool.

The Conceptual Structure Provided by EFA

Table 3 depicts that the average scores of all items from upper-secondary school students are greater than 5, meaning that students considered these corresponding concepts be related to the concept 'chemical equilibrium'.

In the first round of EFA, the value of Bartlett's test of sphericity was 3494.631 ($p < 0.001$) and the value of the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy was 0.930 > 0.70 , which meant that the factor analysis was good. Based on the Eigenvalue greater than 1, four factors that together explained 50.639% of the variance were extracted. However, five items had low communalities with less than 0.40 and low primary factor loadings with less than 0.40: 'Le Chatelier's Principle', 'reaction quotient', 'dynamic equilibrium', 'concentration', and 'feature of chemical equilibrium'. They were thus eliminated according to the suggestion of ignoring the problematic variables (Hair, et al., 2010) so that new factor models were respecified, respectively. Moreover, the item 'establishment of the equilibrium state' having a high cross-loading, the items 'rate of the forward reaction', and 'rate of the reverse reaction' having low primary factor loadings, were found in new factor solutions and also eliminated.

In the last ninth round of EFA, the value of Bartlett's test of sphericity was 2197.521 ($p < 0.001$) and the value of KMO was 0.918. A three-factor model as shown in Table 4 was extracted as an acceptable factor solution, which had 16 concepts and accounted for 52.649% of the variance.

Table 4

The Three-factor Model Obtained from EFA

Factor	Number of items	Range of loadings	Items
1	7	0.501 - 0.801	2) Direction of the shift in chemical equilibrium; 10) Pressure; 13) Chemical equilibrium constant; 14) Chemical reaction rate; 16) Shift of equilibrium state; 20) Limitation of chemical reaction; 21) Degree of conversion at equilibrium
2	6	0.447 - 0.838	7) Condition; 8) Reversibility; 12) Reversible reaction; 15) Forward reaction; 17) Temperature; 18) Reversible process
3	3	0.485 - 0.904	4) Position of equilibrium moved to the right; 5) Reverse reaction; 11) Position of equilibrium moved to the left

Factor 1 mainly includes the concepts related to the quantitative representation and shift of chemical equilibrium, which concepts represent the theoretical or actual state of chemical equilibrium. Factor 2 comprises the concepts having the attribute of 'reversibility' or belonging to the 'condition' category, and the concept 'forward reaction'. Concepts in Factor 3 are related to moving equilibrium in different directions and 'reverse reaction'. The three-factor model with 16 relevant concepts moving represents a complex conceptual structure for students.

The Conceptual Structure (Three-Factor Model) Tested by CFA

The CFA aimed to test the fit between the data and the assumed model, comparing and determining an appropriate and acceptable model. Kline's (2005) recommendations were utilized as guidelines available for acceptable model fit in this research: Root Mean Square Error of Approximation (RMSEA) < 0.08 , Comparative Fit Index (CFI) > 0.90 , Standardized Root Mean Square Residual (SRMR) < 0.10 (Harrington, 2009). The value of Tucker-Lewis index (TLI) greater than 0.90 was also utilized as a cut-off.

The three-factor model (Model 1) from EFA was tested with CFA firstly. The fit indices of Model 1 are presented in Table 5. It was noted that the factor loading of the item 'pressure' was less than 0.40. The results indicated that the model fit of Model 1 was not perfect enough so that Model 1 should be modified. It was an especially common result that the factor loadings of item 'pressure' was below 0.40 when this item was belonging to each factor. Tabachnick and Fidell (2007) contended that factor loadings above 0.45 are fair and between 0.32 and 0.45 are



poor (Harrington, 2009). Item 'pressure' was eliminated based on the above factor loading criterion. As is revealed in Table 5, fit indices of the modified three-factor model (Model 2) also suggested the writers modifying this model.

Table 5
The Fit Indices of Models of EFA and Theoretical Assumptions

Model	S-B χ^2	df	RMSEA	90% confidence interval for RMSEA	CFI	TLI	SRMR
1	242.229*	101	0.068	[0.057, 0.079]	0.879	0.856	0.059
2	220.988*	87	0.071	[0.059, 0.083]	0.878	0.852	0.060
3	168.159*	85	0.057	[0.044, 0.069]	0.924	0.906	0.056
4	191.907*	80	0.068	[0.055, 0.080]	0.898	0.866	0.051
5	137.100*	78	0.050	[0.036, 0.063]	0.946	0.927	0.047

Note: * $p < 0.001$

The modification index provided by Mplus suggested the writers adding two error covariances between error terms for item 'position of equilibrium moved to the left' and 'reverse reaction', and for item 'reversibility' and 'forward reaction'. Although researchers recommended the user to be aware of the model identification problems, they also advised the user to take appropriate action on the correlated error terms if justified by theory (Hair, et al., 2010). Because the reversible reaction is the basis for the shifted position of chemical equilibrium, the concept 'position of equilibrium moved to the left' has a close relation with the concept 'reverse reaction'. On the other hand, reversibility is the essential feature of a reversible reaction that represents the forward reaction and the reverse reaction. The concept 'reversibility' is closely linked to the concept 'forward reaction'. Therefore, adding the within-construct error covariances between error terms of these items was reasonable. The writers accepted the suggestions from the modification index and derived the new modified three-factor model (Model 3). The model fit results showed in Table 5 indicated that Model 3 could be considered to have a reasonably good fit (RMSEA = 0.057 < 0.08, CFI = 0.924 > 0.90, TLI = 0.906 > 0.90, SRMR = 0.056 < 0.10).

Furthermore, Model 2 (the nested model) was compared with Model 3 (the comparison model) in a chi-square difference test. Difference test scaling correction (cd) was 0.781, and Satorra-Bentler scaled chi-square difference test (TRd) was 97.766, $p < 0.001$. It indicated that the change to Model 2 resulted in a significant improvement in model fit.

Based on these results, as is shown in Figure 1, Model 3 with 3 factors and 15 relevant concepts was appropriate and accepted as the conceptual structure for students. The writers named the factors according to the common meaning of the concepts belonging to their factor. First, Factor 1 was named for 'quantity and shift', and the name of the Factor 2 was 'reversibility and condition'. Finally, Factor 3 was apt to be named 'unidirectional shift'.

The Conceptual Structure (Five-Factor Model) Tested by CFA

In Model 3, Factor 1 and 2 could be considered to have two distinct parts in chemistry, respectively. For example, the concepts of Factor 2 are regarding reversible feature or reaction condition. The writers tried to characterize the conceptual structure for students with a more detailed model and tested its validity. We advised a new five-factor model (Model 4) in which the Factor 1 and 2 for Model 3 were divided into respective two factors. In Model 4, Factor 1 includes items 13, 20, and 21, and Factor 2 is comprised of items 2, 14, and 16. Factor 3 consists of items 8, 12, 15, and 18, and Factor 4 comprises items 7 and 17. Other items 4, 5, and 11 are belonging to the factor 5. Fit indices of Model 4 listed in Table 5 came close to the recommended levels.

The modification index also suggested adding some error covariances between error terms. The writers thus followed the suggestions and set correlated error terms for the items as what has been done in the modification of Model 3. The modified five-factor model (Model 5) is shown in Figure 2. Table 5 depicts that Model 5 could be considered as another appropriate and acceptable model (RMSEA = 0.050 < 0.08, CFI = 0.946 > 0.90, TLI = 0.927 > 0.90, SRMR = 0.047 < 0.10). A Chi-square difference test between Model 4 as the nested model and Model 5 as the comparison model was conducted. Difference test scaling correction (cd) was 0.678, and Satorra-Bentler scaled chi-square difference test (TRd) was 117.964, $p < 0.001$. It represented that Model 5 made a significant improvement in model fit compared with Model 4.



Figure 1
Three-factor Model

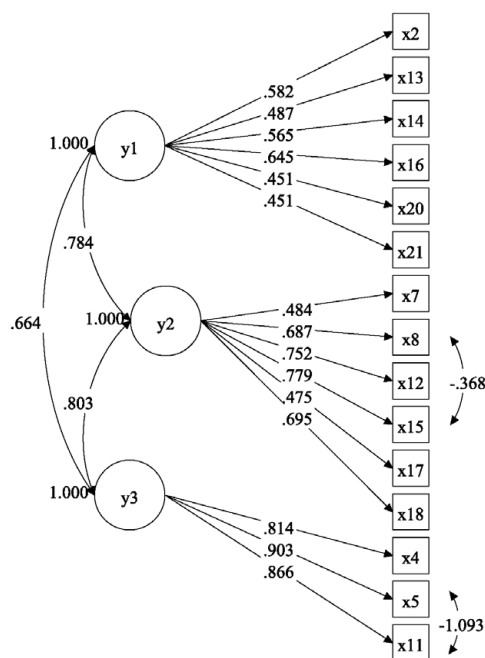
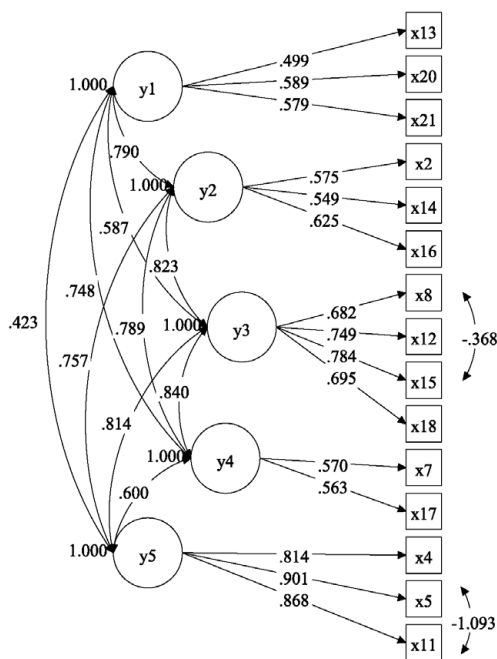


Figure 2
Five-factor Model



Overall, Model 5 with 5 factors and 15 relevant concepts was considered as the conceptual structure for students. The names of the five factors were given as follows. First, the name of the Factor 1 was 'quantitative equilibrium' and that of Factor 2 was 'shift of state'. Second, writers called Factor 3 as 'reversible feature'. Finally, Factor 4 and 5 were yet to be named 'condition' and 'unidirectional shift', respectively.

In general, the model with a lower value of the Bayesian Information Criterion (BIC) means this model is better fitting than other models. BIC values of models revealed that the model fit of Model 5 (BIC = 11595.839) was fitter than that of Model 3 (BIC = 11600.467). It meant that Model 5 derived from Model 3 and 4 could better represent the conceptual structure for students. Although Model 5 had a better structure, the conceptual structures that comprised three-factor or five-factor were all reasonable and acceptable, based on the combination or separation of concepts. Following these factor analysis results, we can deeply understand these conceptual structures of chemical equilibrium held by upper-secondary school students.

Discussion

This exploratory research utilized factor analysis to identify and examine the conceptual structure of chemical equilibrium in upper-secondary school students, determining a three-factor model and a five-factor model. These models represented the extracted relation between the relevant concepts. The analysis method adopted in this research also studied a brand-new framework that could represent the conceptual structure for students. More attention should be put on the research process and findings.

The Concept Pool

It is important to provide researchers and students with a high-quality concept pool having meaningful and accurate concepts. In previous research studies (Gorodetsky & Hoz, 1985; Gussarsky & Gorodetsky, 1988; Wilson, 1994, 1996), concept pools were acquired not by the statistical results of large-sample surveys, but by researchers' private judgments. To avoid the negative effects of personal subjective judgments, the present research was quantitatively oriented in selecting the relevant concepts to constitute a reasonable concept pool. As a result, twenty-four relevant concepts represented chemistry research and teaching practice experts' collective understanding.

On the other hand, some concepts in the concept pools did not have a direct relation to chemical equilibrium in previous research studies. In contrast, the concepts utilized in this research are corresponding to different facets of chemical equilibrium.

For the reasons, the concept pool developed by the writers is better justified than other concept pools in previous research studies. Researchers not only can use it as a useful resource to reveal the conceptual structure for upper-secondary school students but also can use it to design other cognitive tasks to acquire students' different understandings of chemical equilibrium in the future.

The Eliminated Concepts

Nine concepts were eliminated in the analysis process because the communalities and the factor loadings of items corresponding to these concepts were small. In general, small communality of an item means that a large amount of the variance in the item is not accounted for by the factor solution, indicating that the item has a low correlation with whole extracted factors. Similarly, low factor loading of an item means the item has a low correlation with the assumed factor provided by the factor solution. If an item is related to multiple factors at the same time, this item is impossible to belong to only one factor and bring high correction to other factors. In other words, factors only have high correlations with a finite number of items so that they cannot explain the eliminated concepts and share their common connotation.

However, the eliminated concepts, including 'Le Chatelier's principle', 'reaction quotient', 'dynamic equilibrium', and other relevant concepts, are important for upper-secondary school students and university students to understand the regular pattern and performance of chemical equilibrium (Huddle & Pillay, 1996; MOE, 2003, 2018; Mutlu & Şeşen, 2016; Quílez-Pardo & Solaz-Portolés, 1995). The concepts 'Le Chatelier's principle', 'concentration', and 'pressure' were also part of the conceptual structure in previous research studies (Gorodetsky & Hoz, 1985; Gussarsky & Gorodetsky, 1988; Wilson, 1994, 1996). We assumed that eliminated concepts existed in students' structural knowledge, but they had to be eliminated according to the criteria of factor analysis.

The Conceptual Structure

Regarded as the conceptual structures of chemical equilibrium, two appropriate and acceptable models had a good fit between the assumption and students' rating data in this research, respectively. The factor analysis results showed that the conceptual structures included only those concepts having close internal relation with each other, and constituted a small-scale organization of concepts. Because the conceptual structures were derived and examined from the rating data of students, they were expected to reflect the latent relation of relevant concepts in students' understanding at the group level.

In the five-factor model, the factors represent five essential categories of concepts, making theoretical sense in chemistry. They are better corresponding to the physical quantity, common behavior, reversible feature, unidirectional change, and influencing condition of chemical equilibrium. In contrast, the three-factor model is more complicated than the five-factor model. The difference between these models is the way they combine concepts. We supposed that the concepts might have some unexplored internal relations to make this general organization of concepts available.

It is generally accepted that a reversible reaction consists of a forward reaction and a reverse reaction. The writers were aware of the item 'forward reaction' categorized to other items having the reversible feature and of the item 'reverse reaction' belonging to the factor 'unidirectional shift'. The findings meant that the students might have their unique understanding. The cause of these high interrelationships between the concepts remains to be further studied.

The factor model can be viewed as an analytical framework employed to understand chemical equilibrium. But more evidence for the open-end survey is needed to identify whether students widely utilize this analytical framework. Compared with the scientific model (shown in Table 2), the three-factor model and the five-factor model are incomplete and simple. If the scientific model is considered as the learning goal, the students should have a more comprehensive understanding of the relation between concepts. Teachers need to provide necessary and supported teaching activities to develop students' understanding of the concepts.

Basing on different concept pools and techniques, the conceptual structure obtained in this research is not suitable to compare with those obtained in previous research studies. However, all the forms of conceptual structure are beneficial for researchers and educators to deeply understand the way students store domain knowledge.



Conclusions and Implications

This research focused on the conceptual structure of chemical equilibrium for upper-secondary school students, using factor analysis to determine the latent structure of relevant concepts. After twenty-four relevant concepts were selected as a high-quality concept pool, a three-factor model and a five-factor model with 15 relevant concepts were derived from the students' rating. The new form of conceptual structure helps understand the features and categories in students' latent organization of concepts.

Based on the overall results, some implications are given. First, teachers can put more attention to students' deeper understanding of the conceptual structure of chemical equilibrium. Specifically, teachers can conduct the concept classification task to make students focus on the classification and composition relation between the relevant concepts, and to identify which factor model in this research is utilized by students. Moreover, teachers can mention the relation between the relevant concepts repeatedly during classroom teaching, and especially emphasize the importance of the eliminated concepts in this research to understand chemical equilibrium. It is beneficial that students fully understand the relation between the relevant concepts.

Second, further research studies regarding the conceptual structure of chemical equilibrium are needed on conducting a misconception survey and problem-solving test. The conceptual structure is connected with the student's comprehension and misconceptions of chemistry. More research is conducive to know the interplay among conceptual structure, misconception, and performance in problem-solving. Additional indicators of the conceptual structure of chemical equilibrium that could be analyzed qualitatively may be sought.

Finally, as a practice example, this research demonstrated the use of factor analysis to provide the latent structure of science concepts for students. Factor analysis is intended as a complementary method to the conceptual structure research. More research utilized factor analysis in the chemical equilibrium or other science concepts can be conducted in the future.

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