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UTILIZING MULTIDIMENSIONAL SCALING TO REPRESENT THE CONCEPTUAL STRUCTURES OF ATOMIC STRUCTURE IN UPPER-SECONDARY SCHOOL TEACHERS AND STUDENTS

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Abstract. *This research aimed to explore the upper-secondary school chemistry teachers' and students' conceptual structures of atomic structure by using multidimensional scaling. Atomic structure is considered to be one of the most difficult concepts in upper-secondary school chemistry course so that the conceptual structure regarding atomic structure held by the learners is necessary to be examined. Based on a questionnaire survey for upper-secondary school chemistry teachers and university chemistry professors, 40 concepts were selected as a useful concept pool of atomic structure. Then, the conceptual structures and the specific classifications of concepts from 168 upper-secondary school chemistry teachers and 336 tenth-grade students were investigated by multidimensional scaling and hierarchical cluster analysis. The results showed that the 3-D solutions were appropriate for the conceptual structures of teachers and students, respectively. Next, the conceptual structure of teachers utilized as an evaluation criterion was more scientific than that of students. The conceptual structure of students with high academic achievement was more scientific than that of the low achievers. Multidimensional scaling utilized to explore students' conceptual structure of scientific concepts can provide a new and benefic form of evidence to understand the concept learning outcome of students.*

Keywords: *atomic structure, conceptual structure, hierarchical cluster analysis, multidimensional scaling*

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Introduction

Conceptual structure is the mental representation of concepts in individuals, which mainly involves the composition of concepts and the relationships among concepts. It is a key research area of cognitive psychology. The process of constructing, modifying and reorganizing the conceptual structure of learners will affect learners' academic performance (Johnson, et al., 1994). Besides, the researchers regarded conceptual structure as a structural assessment of the teaching effect (Ron, et al., 1997). Therefore, exploring the conceptual structure of learners is necessary, in order to understand the storage of concepts in learners and provide a criterion of the conceptual structure for education evaluation.

The measurement of conceptual structure includes three steps: knowledge elicitation, knowledge representation, and evaluation of knowledge representation (Goldsmith, et al., 1991). First, knowledge elicitation means that the researcher measures a learner's understanding of the relationships among a set of concepts via word association (Chi, et al., 1982), card sorting, judgement of the similarities (Shepard & Chipman, 1970) and other approaches. The second step 'knowledge representation' is to obtain some specific representations of the elicited knowledge. Several approaches such as Pathfinder (Acton, et al., 1994), additive tree (Tversky & Hutchinson, 1986), multidimensional scaling (MDS) (Shepard & Chipman, 1970) are applied in this step. Finally, the derived knowledge representations of individuals are evaluated according to the authoritative criterion, such as the expert's organization of concepts in the domain. The measurement steps mentioned above can be applied to the research of conceptual structure regarding scientific concepts.

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Atomic structure is the core concept of chemistry. The ancient philosopher Democritus proposed the naïve atom theory firstly. The theory believed that everything is composed of indivisible particles (i.e., atoms). Atomic structure has gone through the research process of basic models, old quantum theories, and modern quantum mechanics concepts. And this concept is considered to be one of the most difficult basic concepts for students in upper-secondary school and university (Marvin & Gold, 1988; Niaz, 2002; Qian, et al., 2009; Taber, 2003; Tsaparlis, 1997). In order to understand learners' learning outcome of atomic structure deeply and seek effective teaching strategies for abstract concepts, many researchers have conducted researches on atomic structure, such as misconception (Marvin & Gold, 1988; Niaz, 2002; Taber, 2003; Tsaparlis, 1997), mental model (Ibrahim, 2015; Kiray, 2016; Nikolaos, et al., 2017; Nilüfer & Wang, 2016), conceptual structure (Nakiboglu, 2008; Ozata & Ozkan, 2016), and teaching strategies (Everest & Vargason, 2013; Hoffman & Gary, 2015; Mikhail & Maria, 2016; Valdivia, 2019). However, few studies have focused on the internal organization among the relative concepts held by learners. Therefore, utilizing mature research approach of cognitive psychology is beneficial to explore learners' potential conceptual structure of atomic structure. The result could help learners systematically learn the knowledge of atomic structure.

Conceptual Structure and Multidimensional Scaling

The research of conceptual structure is closely related to the research of classification, mainly discussing the categories composed of concepts and the interrelationship amongst the categories. In cognitive psychology, some theories were produced to explain the concept structure. Three theories of conceptual structure based on the similarity are as follows: (1) The classic theory holds that the concept is composed of defining attributes and criterial attributes (Bruner, et al., 1956); (2) The prototype theory believes that the category of exemplars is based on their resemblance to the prototype, which is the central tendency of the characteristics of each example (Rosch & Mervis, 1975); (3) The context theory proposes that the category is a set of valid exemplars and contexts in cognitive system (Medin & Schaffer, 1978). These theories all emphasize that the similarity plays a decisive role in classification. But similarity is a vague concept that lacks objectivity. Therefore, Murphy and Medin (1985) put forward a theory-based concept theory, claiming that the category of concepts is determined by the existing theory that contains a variety of features. The theory emphasizes the representation of the knowledge structure and makes the classification more scientific.

In order to explore the concept organization in science education, researchers utilized factor analysis (Li, 2020; Mai, et al., 2021; Qian, 2008), word-association test (Acarli, 2016), drawing-writing technique (Kurt, 2013), and reaction time technique (Mai, et al., 2021; Tang, 2019; Wang, 2018) to represent the conceptual structures of science concepts. However, multidimensional scaling has received less attention in the research field of science education.

Multidimensional scaling first proposed by Torgerson (1952) is an effective statistical method that visualizes the global relationships between the concepts as conceptual structure. The conceptual structure is presented in the form of a coordinate system based on the similarity or dissimilarity among several concepts and demonstrated the relative distribution of concepts in a low-dimensional space. The specific steps of this method are as follows: (1) Obtain the similarity data or dissimilarity data of the concepts by classification, comparison, or rating; (2) Convert the similarity data or dissimilarity data into distance data; (3) Obtain the spatial relative coordinates and distribution images of the concepts; (4) Determine the number of spatial dimensions from the model parameters and name the spatial dimensions, and then classify the concepts basing on their spatial relative coordinates. Due to the multidimensional representation images having several concepts at short distances, intuitively clustering for concepts is difficult. In order to solve the concept-clustering problems, the spatial coordinate values of concepts can be utilized by hierarchical cluster analysis, making the clustering results more objective.

Multidimensional scaling is widely utilized in the research of economics, cognitive psychology, linguistics, pedagogy and other fields. Its application in pedagogy focuses on the diagnosis of learning effects. For example, Preece (1976) adopted word association test (WAT) to obtain learners' similarity data between the concepts of classical mechanics, and then utilized multidimensional scaling to represent the conceptual structures of those concepts. Besides, Streveler (1994) measured the cognitive structure of 102 undergraduates in three courses. The relations among students' cognitive structures, instruction, and course achievement were analyzed with the help of multidimensional scaling. Furthermore, Huang and Qian (2020) required students to complete the card-sorting task of chemical equilibrium, and conducted multidimensional scaling and cluster analysis on the results. In spite of this, few studies have applied multidimensional scaling to investigate the conceptual structure of science concepts, with the lack of conceptual structure from experts as authoritative evaluation criterion.

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Students' Conceptual Structure of Atomic Structure

Atomic structure is a difficulty of chemistry learning in upper-secondary school. Researchers utilized cognitive psychology-oriented techniques to investigate students' conceptual structure of atomic structure, in order to learn about the organization of concepts in students' mind. For example, Nakiboglu (2018) firstly obtained the concepts related to atomic structure in the upper-secondary school chemistry curriculum as a concept pool. After that, the changes in the conceptual structure on atomic theories from 40 elementary science education students was investigated by word association test before and after a unit of instruction. In Nakiboglu's study, the RC method, Wearn's graphic representations with cut-off point method, and the response frequencies' map method were used for word association test. Moreover, Ozata and Ozkan (2016) selected nine key concepts from the unit of atom and atomic structure, and utilized these concepts to determined the pre-service teachers' perception of atom and atomic structure through word association test. The pre-service teachers' mind maps of atom and atomic structure showed that the relationships between concepts were not express correctly, although the pre-service teachers could associate concepts with one another.

According to the studies above, obtaining the key concepts related to the topic firstly and determining the concept pool is necessary when investigating the conceptual structure of learners. The scope of the concept pool has an impact on the organization of concepts, and ensuring an authoritative and scientific concept pool is essential. Therefore, developing an effective concept pool of atomic structure as common basic research material is benificial for researchers to carry out related research on the conceptual structures of atomic structure.

Secondly, few studies have paid attention to the measurement of the conceptual structure of atomic structure. The studies above only focused on the learners' understanding and mental models of atomic structure, with the lack of in-depth discussion regarding the internal organization among the concepts. In addition, the main method utilized in the studies of the conceptual structure is word association test, lacking other psychometric methods.

As a mature exploratory data analysis technique, multidimensional scaling is able to visualize the interrelationships among a large number of concepts with points in a low-dimensional space. However, few studies have focused on the function of multidimensional scaling and applied it to investigate teachers' and students' conceptual structures of atomic structure. Multidimensional scaling can be a new approach to promote researchers' understanding of the concept organization.

Research Problem

Previous studies lacked the exploration of the internal organization of the concepts regarding atomic structure, and also did not compare the conceptual structures from different groups. This research aimed to utilize the multidimensional scaling to explore upper-secondary school teachers' and students' conceptual structures of atomic structure from new perspective of research. An effective concept pool including the related concepts about atomic structure is necessary to improve the quality of research. Besides, an in-depth comparison helps to understand the concept organization between chemistry teachers' and students' long-term memory and optimize the teaching practices. The specific research questions that guided this research were as follows:

(1) What is the concept pool of atomic structure identified by the rating from upper-secondary school chemistry teachers and university professors?
(2) What are the conceptual structures of atomic structure from upper-secondary school teachers and students, as shown in a three-dimension semantic space?
(3) Are there differences in the conceptual structures of atomic structure among the students with different levels of chemistry academic achievement, and the upper-secondary school teachers?

Research Methodology

General Background

This research conducted the questionnaire surveys for university professors from South China Normal University, upper-secondary school teachers from all over China, and tenth-grade students from five upper-secondary schools in Guangzhou during the 2019-2020 academic year. This research had two parts. The first part of this research was to obtain an effective concept pool of atomic structure. The initial concept pool was acquired referring to Chi-

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nese upper-secondary school chemistry curriculum materials and the formal concept pool was finally determined according to the survey data of upper-secondary school chemistry teachers and university chemistry professors.

The second part of this research was to acquire the conceptual structures of atomic structure. Card sorting of the concept pool was conducted. Participants involved the upper-secondary school chemistry teachers and tenth-grade students. Next, the multidimensional scaling and hierarchical cluster analysis were conducted to obtain the multidimensional representations and the classifications of the concepts, respectively. Finally, the differences in the conceptual structures among different groups of participant were compared.

Participants

In this research, 62 upper-secondary school chemistry teachers and 13 university professors of inorganic chemistry or structural chemistry were invited to participate in the questionnaire survey, selecting the related concepts and constructing the concept pool of atomic structure. From the perspective of upper-secondary school chemistry teaching practice, the upper-secondary school chemistry teachers are the authoritative groups to direct the teaching of concepts. From the perspective of extension and supplement of chemistry learning and education, the university professors of chemistry play an important role in the cross-stage research of concepts. Fifty-nine valid questionnaires from upper-secondary school chemistry teachers (Group 1; recovery rate: 95.2%) and 11 valid questionnaires from university professors (Group 2; recovery rate: 84.6%) were collected, respectively. The two groups above judged the related concepts of atomic structure from different aspects, making the concept pool have a high and scientific content validity.

After determining the concept pool, 179 upper-secondary school chemistry teachers all over the country were invited to finish the questionnaire survey on the task of card sorting regarding atomic structure. They had participated in the national backbone teacher training project, with a total of 168 valid samples (Group 3; recovery rate: 93.9%). The conceptual structure obtained from chemistry teachers could be utilized as a criterion to evaluate students' conceptual structures.

Furthermore, tenth-grade students from five upper-secondary schools in Guangzhou were invited to participate in the questionnaire survey of conceptual structure. The students were divided into two groups based on the admission scores of Guangzhou's upper-secondary school entrance examination in 2018. The first group of the students came from three schools with high admission scores, with a total of 169 valid samples (Group 4a; recovery rate: 93.4%). Another group of students came from two schools with lower admission scores, with a total of 167 valid samples (Group 4b; recovery rate: 90.2%). Before participating in the survey, all the students above had studied the chapter of atomic structure in a chemistry compulsory module (Wang & Zheng, 2019). They understood the aim of this research and agreed to finish the survey.

Instrument and Procedures

The research instruments utilized in this research were concept relatedness rating questionnaire and card sorting questionnaire. In the concept relatedness rating questionnaire, 57 concepts related to atomic structure in chemistry module were selected as the items, according to the chemistry curriculum standards of China (MOE, 2003, 2018), chemistry textbooks of a compulsory module (Wang & Zheng, 2019; Wang, 2019; Wang, 2019), and a general college entrance examination outline (National Education Examinations Authority, 2018). A 7-point Likert scale was utilized to rate the degree of relatedness between each item and the concept of atomic structure, respectively. The score from 1 to 7 indicated that the degree of relatedness increases gradually. The card sorting questionnaire contained two parts: the classification of the items received in the cocept pool and the reason for classification.

The research procedure consisted of two steps. First, in order to determine an effective concept pool of atomic structure, the concept relatedness rating questionnaire was sent to the upper-secondary school chemistry teachers (Group 1) and the university professors of inorganic chemistry or structural chemistry (Group 2). Among them, the former were invited to rate each item's degree of relatedness to the concept of atomic structure. And the latter were invited to tick the items shown on the questionnaire, which could make up a concept pool of atomic structure. Then, the item would be accepted as a related concept in the formal concept pool when the average score rated by upper-secondary teachers was greater than 5 or the frequency from the university professors was greater than 7. The frequency means how many professors believed that the concept could be one part of the concept pool.

The second step was to send the card sorting questionnaire to the upper-secondary school chemistry teach-

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ers (Group 3) and the tenth-grade students (Group 4a and 4b), in order to investigate their conceptual structures of atomic structure. They were asked to classify the items in the concept pool freely and write down the reasons why they made the decisions. Each item was stipulated to be classified into one category without being omitted or repeatedly selected. The task should be finished in 20 minutes without discussing with each other.

Data Analysis

Data analysis consisted of three stages. First, the average score of items based on the rating data were calculated via descriptive statistics of SPSS 24.0 in the process of determining the concept pool. Second, the original data of card sorting was converted into a 40 x 40 dissimilarity matrix through the computer program. If the items were classified into the same category, then the intersection of the two items was recorded as 0 in the matrix; if not, the intersection was recorded as 1. Then, multidimensional scaling in SPSS 24.0 was conducted to determine the organizational dimensions of the conceptual structure of atomic structure. Solutions of different dimensions, pressure values, and coordinate values of concepts in different dimensions were obtained. Finally, to further interpret the multidimensional scaling result, hierarchical cluster analysis of SPSS 24.0 was utilized to analyze the three-dimensional coordinates of the items by Ward's method, which utilizes squared Euclidian distances to represent the similarity among items and obtain dendrograms of clustering.

Research Results

The Concept Pool of Atomic Structure

Table 1 shows the scores given to 57 items of atomic structure by 59 upper-secondary school chemistry teachers and the frequencies by 11 university chemistry professors. After excluding 17 items (from I41 to I57), the remaining 40 items (from I1 to I40) iems were selected as a concept pool of atomic structure.

Table 1
The Scores and Frequencies of Items of Atomic Structure

Number	Item	Upper-secondary teachers		University professors		Whether selected
		M	*SD*	Recognition frequency	Recognition ratio	
1	Particles	5.931	1.532	7	.64	Yes
2	Proton	5.828	1.749	11	1.00	Yes
3	Proton number	5.966	1.521	11	1.00	Yes
4	Periodic table of elements	6.086	1.537	7	.64	Yes
5	Electronic configuration	6.276	1.268	11	1.00	Yes
6	Valence	6.121	1.403	7	.64	Yes
7	Atom	6.103	1.483	11	1.00	Yes
8	Neutron	5.500	2.002	11	1.00	Yes
9	Outer-shell electron number	6.397	1.075	11	1.00	Yes
10	Period	5.655	1.753	7	.64	Yes
11	Atomic structure sketch map	6.466	1.080	10	.91	Yes
12	Molecule	5.052	1.820	6	.55	Yes
13	Relative atomic mass	5.052	1.959	9	.82	Yes
14	Group	5.190	1.801	6	.55	Yes
15	Outermost electrons number	6.103	1.347	10	.91	Yes
16	Atomic nucleus	5.552	1.921	10	.91	Yes
17	Element	5.431	1.865	10	.91	Yes

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Number	Item	Upper-secondary teachers		University professors		Whether selected
		M	*SD*	Recognition frequency	Recognition ratio	
18	Atomic number	5.603	1.854	10	.91	Yes
19	Outer-shell electron	5.741	1.671	11	1.00	Yes
20	Nuclear charge number	5.759	1.668	11	1.00	Yes
21	Ion	5.586	1.612	8	.73	Yes
22	Mass number	5.172	2.045	7	.64	Yes
23	Short period	5.241	1.913	10	.91	Yes
24	Nuclide	5.310	1.958	6	.55	Yes
25	Metallicity	5.672	1.741	10	.91	Yes
26	Ability to lose electrons	6.190	1.131	11	1.00	Yes
27	Ionic bond	5.724	1.542	6	.55	Yes
28	Neutron number	5.276	1.908	5	.45	Yes
29	Electron shells number	6.086	1.240	10	.91	Yes
30	Isotope	5.138	2.004	4	.36	Yes
31	Non-metallicity	5.810	1.432	10	.91	Yes
32	Periodic law of elements	6.138	1.330	8	.73	Yes
33	Covalent bond	5.828	1.523	6	.55	Yes
34	Halogen	5.328	1.858	9	.82	Yes
35	Main group	5.466	1.759	7	.64	Yes
36	Elemental properties	5.948	1.527	9	.82	Yes
37	Ability to get electrons	6.172	1.216	11	1.00	Yes
38	Atomic radius	5.707	1.654	9	.82	Yes
39	Alkali metal	5.569	1.788	5	.45	Yes
40	Atomic structural model	6.069	1.543	9	.82	Yes
41	Mixture	3.241	2.273	4	.36	No
42	Simple substance	4.086	2.146	4	.36	No
43	Relative molecular mass	4.810	1.896	5	.45	No
44	Positive charge	4.828	2.001	7	.64	No
45	Compound	4.259	2.091	5	.45	No
46	Element mass ratio	3.948	2.131	4	.36	No
47	Negative charge	4.810	1.887	7	.64	No
48	Atomic group	4.603	1.973	0	.00	No
49	Oxide	4.034	2.069	4	.36	No
50	Element mass percentage	3.879	2.145	3	.27	No
51	Elemental symbol	4.448	2.583	7	.64	No
52	Pure substance	3.345	2.275	4	.36	No
53	Chemical formula	4.828	2.095	3	.27	No
54	Transition elements	4.000	2.160	7	.64	No
55	Long period	4.517	2.130	7	.64	No
56	Noble gases	4.845	2.033	5	.45	No
57	Quark	2.966	1.108	3	.27	No

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The Results Determined Through Multidimensional Scaling

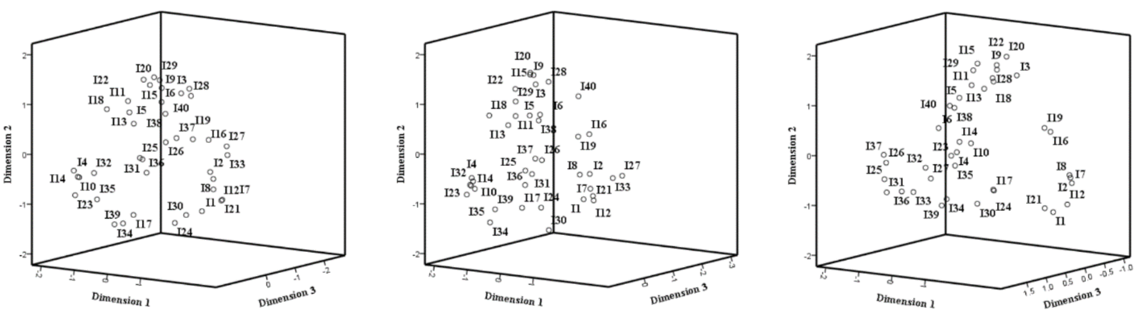
The multidimensional scaling results showed that three dimensional solutions were appropriate for the conceptual structures of Group 3, Group 4a, and Group 4b. Stress and R^2 values are represented in Table 2. The Stress value is utilized to describe the fitting relationship between the data and the model: stress ≤ .05, an excellent fit; .05- .10, a good fit; Stress > .10, a fair fit; Stress < .20, an acceptable fit (Kruskal, 1964). The R^2 value represents the proportion of the original data interpreted by the low dimension. It is generally considered that the value greater than .6 is acceptable, and closer to 1 is better (Meyer, et al., 1992). The results demonstrated that all Stress values fell within the accpeptable range and R^2 values were indicative of good fit.

The three-dimensional representation of the conceptual structure is displayed in Figure 1. In order to further analyze each dimension, Figures 2, 3, and 4 present different groups' two-dimensional projections of the three dimensional solutions.

Table 2
Stress and R^2 Values Determined by Multidimensional Scaling

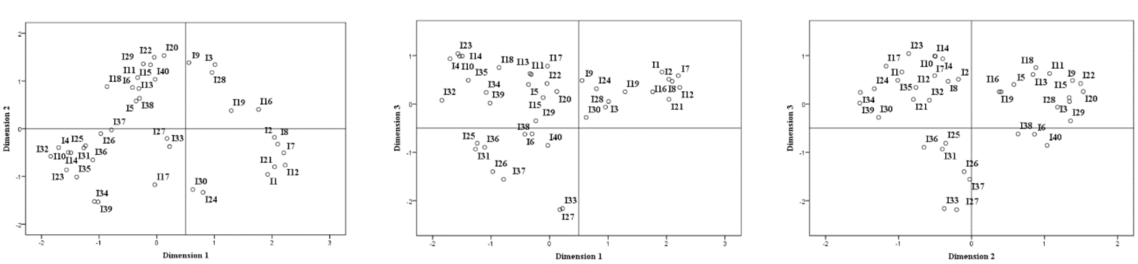
Group	Model Fit	
	Stress	R^2
Group 3	.10917	.91587
Group 4a	.09755	.93754
Group 4b	.09984	.93271

Figure 1
The Three Dimensional Representation of the Conceptual Structures



(a) Group 3 (b) Group 4a (c) Group 4b

Figure 2
Two-Dimensional Projections of the Three Dimensional Solution of Group 3



(a) Dimensions 1 (horizontal) and 2 (vertical) (b) Dimensions 1 (horizontal) and 3 (vertical) (c) Dimensions 2 (horizontal) and 3 (vertical)

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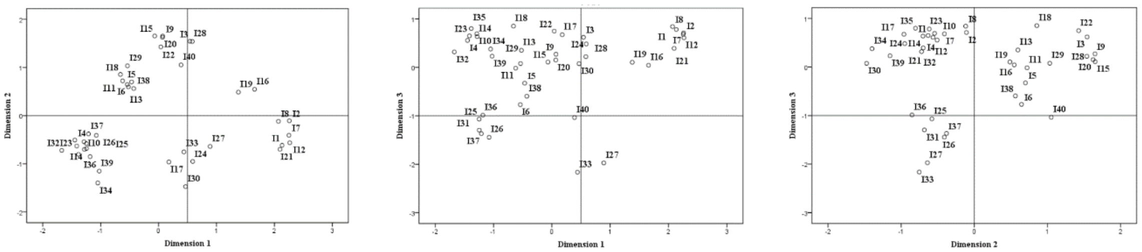
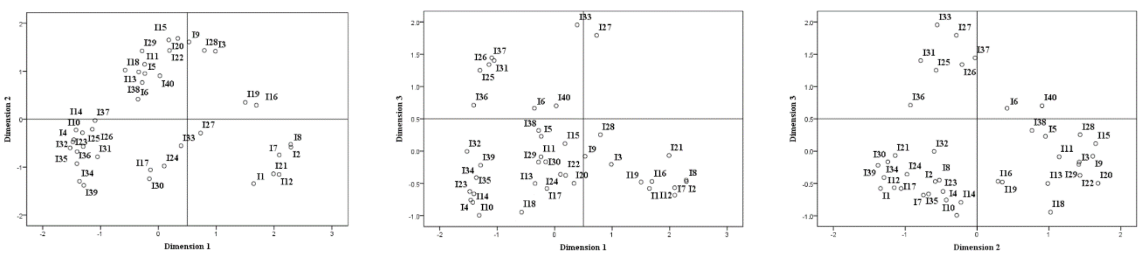
Figure 3
Two-Dimensional Projections of the Three Dimensional Solution of Group 4a



(a) Dimensions 1 (horizontal) and 2 (vertical) (b) Dimensions 1 (horizontal) and 3 (vertical) (c) Dimensions 2 (horizontal) and 3 (vertical)

Figure 4
Two-Dimensional Projections of the Three Dimensional Solution of Group 4b



(a) Dimensions 1 (horizontal) and 2 (vertical) (b) Dimensions 1 (horizontal) and 3 (vertical) (c) Dimensions 2 (horizontal) and 3 (vertical)

As shown in Figure 2 to 4, three groups' conceptual structures of atomic structure contain the same dimensions. According to the common meaning of the items in the same dimension, the names of three dimensions were given as follows. First, the name of the first dimension was 'spatial arrangement / structure particles'. The items on the left were related to the spatial arrangement of particles. To the right, the items were related to atomic structure particles. Second, the name of the second dimension was 'macro / micro'. The items on the left were at the macro level, while the items on the right were at the micro level. Third, the last dimension was apt to be named 'elemental properties / periodic table of elements'. The items on the upper side were related to the elemental properties, the others on the lower side were related to the periodic table of elements.

By comparing the results from the two-dimensional projections of three groups, it was clear that there was no obvious difference in the distribution of items in Dimension 2. Second, in Dimension 1, the item 24 (nuclide) and the item 30 (isotope) were closer to the structure particles dimension in Group 3 than those in Group 4a and 4b. Third, in Dimension 3, the distribution boundaries of different clusters of items were clearer. The distribution of similar items was more concentrated in Group 3, followed by Group 4a, and the last was Group 4b.

The Results Determined Through Hierarchical Cluster Analysis

The dendrograms of hierarchical cluster analysis are shown in Figure 5. Forty items were divided into two large clusters which splitted into six or seven sub-clusters. Table 3 represents the classifications obtained by cluster analysis of different groups.

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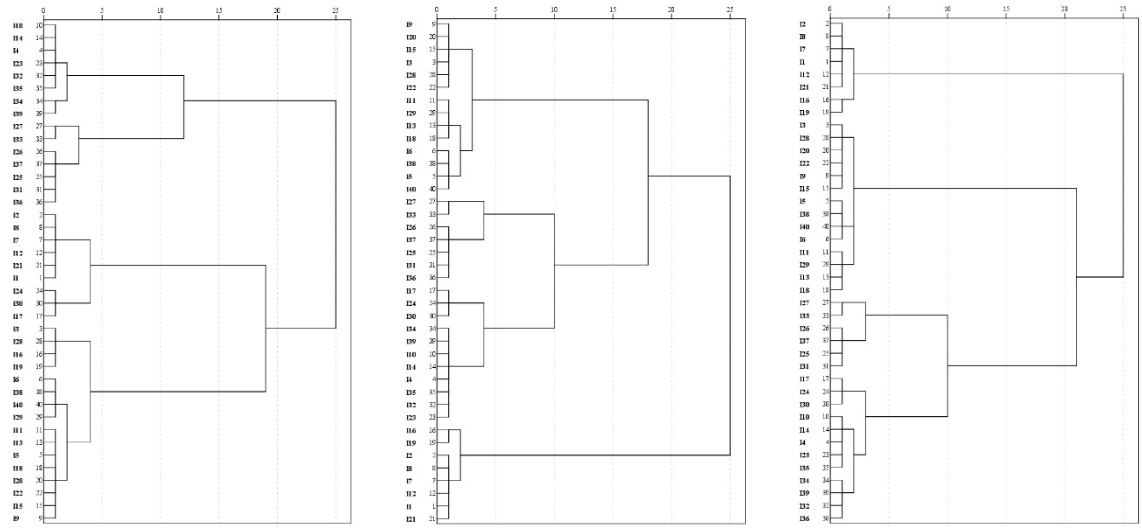
Figure 5

The Dendrograms Obtained by Hierarchical Cluster Analysis of Different Groups



(a) Group 3 (b) Group 4a (c) Group 4b

Table 3

The Classifications Obtained by Hierarchical Cluster Analysis of Different Groups.

Group	Large clusters	Sub-clusters
Group 3	Structure particles and their spatial arrangement	(1) Structure particles; (2) Classifications of atoms; (3) Atom basic constitution; (4) Atomic structure arrangement information
	Elemental properties	(5) Particles interaction; (6) Elemental properties; (7) Periodic table and periodic law of elements
Group 4a	Structure particles	(1) Structure particles
	Spatial arrangement and elemental properties	(2) Particles quantity; (3) Atomic structure arrangement information; (4) Particles interaction; (5) Elemental properties; (6) Classifications of atoms ; (7) Periodic table and periodic law of elements
Group 4b	Structure particles	(1) Structure particles
	Spatial arrangement and elemental properties	(2) Atomic structure arrangement information; (3) Particles interaction; (4) Elemental properties; (5) Classifications of atoms ; (6) Periodic table and periodic law of elements

Table 3 represents that the items of Group 3 are respectively divided into two large clusters. A cluster included the items regarding the structure particles and their spatial arrangement, and the other cluster consisted of the items concerning elemental properties. However, two different large clusters in the classification of Group 4a and 4b were found. A cluster comprised the items regarding the structure particles, and the other cluster included the items related to the spatial arrangement and elemental properties.

The items in Group 3 are subdivided into sub-cluster 'structure particles', 'classifications of atoms', 'atom basic constitution', 'atomic structure arrangement information', 'particles interaction', 'elemental properties' and 'periodic table and periodic law of elements'. Compared with Group 4a and 4b, Group 3 had an additional sub-cluster 'atom basic constitution'.

By comparing the content of the sub-clusters, the classifications of Group 4a and 4b are more consistent. The items are divided into sub-cluster 'structure particles', 'atomic structure arrangement information', 'particles interaction', 'elemental properties', 'classifications of atoms' and 'periodic table and periodic law of elements' in both groups. Furthermore, Group 4a has an additional sub-cluster 'particles quantity'.

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Discussion

After determining the concept pool of atomic structure in upper-secondary school chemistry compulsory module, this research not only investigated the conceptual structures of upper-secondary school teachers and students by utilizing multidimensional scaling and hierarchical cluster analysis, but also compared the differences in their conceptual structures of atomic structure. Three parts of the results were discussed as follows.

The Quality of Concept Pool

The construction of study on atomic structure involves numerous related concepts, which makes it difficult for students to grasp the key points of learning and increases the learning burden. Therefore, it is necessary to filter out a few but useful concepts related to atomic structure to constitute the concept pool before carrying out the conceptual structure research. In previous study (Nakiboglu, 2008), the concept pool was determined by the researcher's personal subjective judgement with a lack of the statistical data from large-sample surveys. The selection of the concept pool in this research not only referred to authoritative texts, but also comprehensively considered the opinions of experts in the field of chemistry teaching or chemistry research. Therefore, the concept pool was useful and authoritative scientific. Researchers can make full use of this concept pool to carry out other empirical investigations related to the conceptual structure of atomic structure.

Teachers' Conceptual Structure of Atomic Structure

Teachers' conceptual structure of atomic structure was highly scientific and authoritative. The reasons were as follows: First, the conceptual structure of teachers' not only followed the scientificity of the knowledge of chemistry, but also conformed to the order of the textbooks. Previous study (Brown, 2009) proposed that as an auxiliary tool for teaching, the functions and characteristics of the textbooks would affect the teaching of teachers. Remillard (2005) also made a more detailed interpretation of the relationship between textbooks and teachers. He believed that teachers would select, adapt and implement the content of textbooks based on their own understanding of teaching, students' learning conditions and teaching situations. In addition, the characteristics of textbooks compilation ideas and layout structure would also affect teachers' understanding of subject knowledge. Teachers' conceptual structure obtained in this research can also provide evidence for the above study. For example, in upper-secondary school chemistry compulsory textbooks, the chapter of the knowledge of atomic structure related units is presented in the order of atomic structure, electronic configuration, periodic table, periodic law and element properties. Group 3 classified the items related to atomic structure and electronic configuration into one large cluster, and classified the items related to periodic table, periodic law and element properties into another large cluster, which was consistent with the order of the textbooks. Second, due to the large sample size of teachers surveyed in this research, the conceptual structure had high reliability and validity. Third, the participants in the Group 3 all came from the national backbone teacher training project, which showed that the conceptual structure of Group 3 obtained in this research had a certain degree of authority.

Based on the above points of view, teachers' conceptual structure could be utilized as an evaluation criterion. Other researchers can subsequently compare the conceptual structure of the participants with Group 3 in this research, and evaluate the quality of the conceptual structure based on the similarity. More importantly, in view of the differences between the two groups' conceptual structures, it is possible to understand the shortcomings of students in the process of learning atomic structure.

Students' Conceptual Structures of Atomic Structure

Students' conceptual structures of atomic structure were similar to that of teachers' in certain aspects. Their conceptual structures of atomic structure contained the same three dimensions, namely 'spatial arrangement / structure particles', 'macro / micro' and 'elemental properties / periodic table of elements'. And their classifications obtained by hierarchical cluster analysis involved the same five sub-clusters: 'structure particles', 'atomic structure arrangement information', 'particles interaction', 'elemental properties' and 'periodic table and periodic law of ele-

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ments'. However, compared with teachers' conceptual structure, student's result had certain deficiencies in terms of scientificity, which were specifically manifested in the following aspects.

From the perspective of the results represented by multidimensional scaling, compared with the evaluation criterion, students' conceptual structures were mainly different in the following two points. First, the distribution boundaries of the items in different clusters were unclear. From the results of Group 4a and 4b represented by multidimensional scaling, items related to 'elemental properties' and items related to 'periodic table of elements' overlapped somewhat on the distribution boundary, which was consistent with previous study. Previous study (Chu, 2017) has shown that many students frequently learned the contents of the periodic table by rote learning. They usually misunderstood the relationship between 'atomic structure', 'periodic table', and 'element properties'. However, learning element properties should be based on a deep understanding of atomic structure. After determining the position of the element in the periodic table by analyzing the arrangement of electrons outside the nucleus, students ought to judge the changing law of element properties in conjunction with the law of element periodicity. Therefore it is necessary to carry out targeted teaching methods in the follow-up to promote students' understanding of these three types of concepts.

Second, the distribution of individual item in the three-dimensional representation was not accurate. For example, students didn't classify item 24 (nuclide) and item 30 (isotope) into the dimension 'structure particles', especially the students in Group 4b. Previous study (Zhang, 2017) has shown that students tended to confuse the two concepts of 'isotope' and 'nuclide', and misunderstand their definitions. The conceptual structure of the Group 4a and 4b obtained in this research can also provide evidence for the above study. According to the textbook definition, different atoms of the same element with the same number of protons but different numbers of neutrons are called isotopes, and an atom with a certain number of protons and neutrons is called a nuclide. It can be seen that the essence of isotopes and nuclides is atoms, which should belong to the cluster 'structure particles'. Teachers' classification results of these two items were more scientific. In contrast, students' were not appropriate.

According to the classifications obtained by hierarchical cluster analysis, students' conceptual structures mainly had the two following deficiencies. First, students mainly classified items from the perspective of whether they were test sites without scientificity. Different from teachers, students classified items into 'structure particles' and 'spatial arrangement and elemental properties' two large clusters. The items related to 'structure particles' are relatively abstract and rarely chosen as test sites, which caused students to ignore such items. On the contrary, the items related to 'element properties' are frequently tested in upper-secondary school chemistry examination, and students tend to subconsciously classify such items into the same cluster.

Second, it could be seen from the results of sub-cluster classification that Group 4a and 4b lacked the sub-cluster 'atom basic constitution' compared with Group 3. This also showed that students didn't pay much attention to the basic constitution of atom. As the enlightenment knowledge of learning atomic structure, the concepts related to atomic basic constitution were first presented in the textbook, which had laid an important foundation for the learning of the chapter of atomic structure. Therefore, its importance is self-evident. In addition, compared with Group 4b, Group 4a classified items related to quantity into the sub-cluster 'particle quantity' separately. This result might be due to the fact that students with high academic achievement had quantity awareness than students with lower academic achievement.

Comparison of Research Approaches to Conceptual Structure

With the help of the multidimensional scaling, the conceptual structure of atomic structure was produced. Multidimensional scaling has several advantages over other methods.

For the amount of data, compared with the previous study (Nakiboglu, 2018) by using the word association test, this research enabled the participants to make corresponding responses to each pair of related concepts, and could avoid the problem of longer test time due to the large number of participants.

Second, for the classification of concepts, Mai, Qian, Li, and Lan (2021) conducted factor analysis on the rating data of relatedness between concepts to determine the conceptual structure. In contrast, this research utilized multidimensional scaling with the data of card sorting to determine the organizational dimensions of the conceptual structure. This method of eliciting conceptual structure was more reflective of participants' underlying classifications of concepts.

Third, for the estimation of distance between concepts, Mai, Qian, Lan, and Li (2021) utilized the reaction time technique to measure the straight-line distance between the core concept and related concept. On this basis, this

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research could also visualize the relationship between the related concepts and the concept 'atomic structure' in three-dimensional space, which could better reflect the spatial organization of the concepts.

In general, multidimensional scaling shows intuitive spatial features in conceptual structure, which is obviously helpful for understanding learners' concept organization.

Conclusions and Implications

This research utilized the multidimensional scaling to represent teachers' and students' conceptual structures of atomic structure and provided a certain reference value for the research on the conceptual structures of chemistry. Before the investigation began, 40 concepts were determined as the effective concept pool of atomic structure. Next, the conceptual structures of chemistry teachers and tenth-grade students in upper-secondary school were tested with the help of multidimensional scaling, and the results showed that three-dimensional solutions were appropriate. In addition, this research also utilized hierarchical cluster analysis to further explore the classifications of concepts in their conceptual structures. In conclusion, teachers' conceptual structure could be used as an evaluation criterion. The conceptual structure of students with high academic achievement was more scientific than that of the low achievers.

Based on the overall results, the following implications were given. First of all, in response to the request of the chemistry curriculum standards of China, teachers ought to make full use of a variety of evaluation methods to diagnose students' conceptual structures on core concepts, and adopt effective teaching strategies to improve students' conceptual understanding based on the diagnostic results. This research represented students' conceptual structures of atomic structure by multidimensional scaling, finding that students had certain misunderstandings in conceptual classification. Therefore, teachers can guide students to draw conceptual diagrams in subsequent teaching so as to provide help for building a systemic conceptual structure.

Second, combining multidimensional scaling and hierarchical cluster analysis to analyze the conceptual structure is worthy of reference in science concept research. This method can not only obtain the spatial relative coordinates and distribution images of the concepts, but also acquire a more scientific classification result by utilizing hierarchical cluster analysis. This research provided a new method for the research on conceptual structure in chemistry subject, and also had a certain reference value for subsequent researchers to carry out the research on conceptual structure in science subject.

Third, it is necessary to explore the development of the conceptual structure of students in the learning process of the chapter of atomic structure in the follow-up work. Although this research compared the gap between the conceptual structures of students and teachers, it is still unclear which factors affected the conceptual structures of students. The formation of the conceptual structure includes the process of construction and continuous improvement, which will be affected by new and old knowledge. Therefore, it is necessary to explore the vertical development of the conceptual structure of atomic structure among students in the junior middle school section, upper-secondary school compulsory section, and optional compulsory section. The research can provide references for teachers to effectively carry out the overall teaching design of the chapter of atomic structure.

Declaration of Interest

Authors declare no competing interest.

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