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STUDENTS' CONCEPT ORGANISATION REGARDING CHEMICAL EQUILIBRIUM IN UPPER-SECONDARY EDUCATION: BASED ON REACTION TIME TECHNIQUE

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Abstract. *Chemical equilibrium is so important domain knowledge in chemistry that the corresponding organisation of concepts in students has been an interesting but unsolved issue. A deeper understanding of how students organise the relevant concepts in long-term memory is beneficial to develop more targeted teaching practices. This research utilized the reaction time technique as a new approach to exploring upper-secondary school students' organisation of concepts regarding chemical equilibrium. A category judgment task involving 247 Chinese twelfth-grade students from two upper-secondary schools was conducted. The results showed that a significant difference was between the reaction time of concept dimensions. The mean reaction time of the dimension 'reversible reaction' was the shortest, but the dimension 'representation of state' had the longest mean reaction time. Next, there was no significant difference in the organisation of concepts between students studying chemistry at different levels of academic achievement. These findings provide a new and essential picture to deeply understand the organisation of concepts regarding chemical equilibrium and help focus on the relations between some relevant concepts. This research represents that the reaction time technique can be utilized in the research on organisation of science concepts.*

Keywords: *category judgment task, chemical equilibrium, organisation of concepts, reaction time*

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Introduction

How the concepts are organised in an individual's mind is an interesting and essential research issue. Cognitive psychologists have developed theories to describe the organisation of concepts (Foster, 2009; Solso, et al., 2014) and some techniques representing different forms of the organisation in an individual's memory (Jonassen, et al., 1993). In the classical theory perspective, they have utilized the semantic network to explain the way concepts organise (Collins & Quillian, 1969; Quillian, 1968). In the semantic network, the nodes are considered as the concepts or propositions, and the links connecting them represent the order and propositional relationship (Norman, et al., 1976). Theme-relevant concepts are distributed around the target concept. Employing the assumption of the semantic network, science education researchers have explored various forms of science concept organisation in students' minds (Geeslin & Shavelson, 1975; Qian, 2008; Soika & Reiska, 2014).

Chemical equilibrium has been considered as a difficult learning topic in chemistry (Bergquist & Heikkinen, 1990; Finley, et al., 1982; Johnstone, et al., 1977). Students need to know various abstract and relevant concepts in the knowledge of chemical equilibrium. To help students more easily to learn chemical equilibrium, chemistry education researchers have focused on students' learning progress and outcome of chemical equilibrium (Akkus, et al., 2011; Barke, et al., 2009; Chiu, et al., 2002; Hackling & Garnett, 1985; Özmen, 2008).

Especially, the organisation of concepts as a learning outcome in long-term memory is the foundation of declarative knowledge, affecting conceptual understanding. Chemistry education researchers have paid attention to the organisation of concepts revealing the distribution and distance among the concepts. For example, Wilson (1994, 1996) required upper-school students to finish the concept map from some selected concepts related to chemical equilibrium. Students wrote the considered and directed connection among the relevant concepts in the concept maps

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but easily missed some connection between the relevant concepts and the concept 'chemical equilibrium'. Next, Gussarsky and Gorodetsky (1988, 1990) utilized word association surveys to acquire the most relevant concepts of chemical equilibrium in upper-secondary school students. The results only represented the concepts and their categories in the semantic network, but not represented the connection distances between the relevant concepts and the concept 'chemical equilibrium'. It was beneficial to collect students' behavioural results in a special method and show their organisation of concepts at the group level, highlighting the information concerning the distances between concepts and gaining a global perspective. Chemistry education researchers can reflect on the existing research results and promote the teaching practice of chemical equilibrium.

Furthermore, chemistry education researchers have found a close relationship between the organisation of concepts regarding chemical equilibrium and the academic level that students had (Gussarsky & Gorodetsky, 1988, 1990; Wilson, 1994, 1996). It has been unclear how the differences between the organisations of concepts acquired by the new approach form students with different levels of academic achievement in chemistry. The answer to this unsolved issue can help chemistry education researchers learn more about the relationship and identify the possible influencing factors.

Spreading Activation Theory

Based on the assumption of the semantic network, Collins and Loftus (1975) developed the spreading activation theory to explain the change of spreading activation in an individual's information retrieval. As spreading activation theory assumed, the attenuation of spreading activation is a complicated process influenced by the semantic similarity between concepts. Semantic similarity refers to the number of properties belonging to concepts. If those concepts have more common properties, they have a higher level of semantic similarity so that they are more linked closely and related internally. As a result, the distances between those concepts are shorter in the semantic network. Moreover, the frequency of concept usage also affects the strength of the links in the semantic network. A highly used relevant concept and the target concept are expected to have a higher strength of the link and a shorter distance. In brief, the number of properties, the level of semantic similarity, the strength of the links, the degree of relatedness, and the distance between concepts are interrelated.

When an individual is stimulated by the input information (such as words), the activation of the nodes and the search in the semantic network spread through the links connected to those nodes to other nodes, and the lexical processing occurs. The recognizing, recalling, and classifying all require semantic activation and search for the closest nodes as relevant concepts in the semantic network firstly. The spreading activation theory assumes that the activation of the nodes decreases with low strength of the links and long spreading distances. For example, an irrelevant concept has a long distance from the target concept. The activation of the node regarding this irrelevant concept is attenuated so that the time of spreading activation towards this node becomes long. As a result, the individual utilizes a long time to recognize, recall, or classify this irrelevant concept. In other words, the more related to the target concept a concept is, the shorter time the spread of activation has.

If the spreading time of relevant concept is measured respectively by a research approach, the distance between the relevant concept and the target concept and the degree of relatedness between them can be inferred (Collins & Loftus, 1975; Danguecan & Buchanan, 2016; Recchia & Jones, 2012). The behavioural results also can be utilized to represent a corresponding organisation of concepts that may exist in the semantic network.

Reaction Time Technique

The reaction time technique is a fundamental research approach in psychology, providing the individual's response time as a behavioural result to represent the cognitive process (Jiang, 2012; Kantowitz, et al., 2008; Solso, et al., 2014). The reaction time is the interval of time between a signal and a reaction to it when a stimulus appears in front of the participant and then the participant begins to make an act of response. The reaction time is measured by the professional software in the computer, which time is between the stimulus appears on the computer screen and then the participant presses on the button of a computer keyboard. Generally speaking, the more complex the cognitive process that the participant experiences, the longer the reaction time. Psychologists can infer the stages of the cognitive process through the reaction time of behavioural experiments.

In the research studies of science education, researchers have utilized reaction time technique to explore students' science learning. The research topics were concerning students' persistence of the naive science concept

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or intuitive reasoning on the science concept, including the research studies of matter classification (Babai & Amsterdamer, 2008), living thing classification (Babai, et al., 2010), physical phenomena (Potvin, et al., 2015), probability (Babai, et al., 2006), geometrical shape (Babai, et al., 2012), and electricity (Zhu, et al., 2019).

Various kinds of tasks elicit an individual's specific cognitive process to address different research issues. The category judgment task requires the participants to judge the relations between the concepts utilized as stimuli and a special category utilized as the target (Jiang, 2012). The essence of the task is to identify the relatedness between the tested concepts and the target concept. The more closely the tested concept is related to the target concept, the shorter the reaction time. Considering the reaction time as a function of the relative distance, the tested relevant concept is expected to have a short distance from itself to the target concept in the semantic network.

Previous research studies have employed category judgment task to collect the data for the research of semantic distance regarding the chemistry concepts in upper-secondary school students, such as the concepts 'ionic reaction' (Wang, 2018), 'redox reaction' (Tang, 2019), and 'galvanic cell' (Li, 2020). They have inferred the relative distance between the relevant concept and the target concept from the length of reaction time, but not combined all relative distances to explore and visualize the latent organisation of the concepts.

It is necessary to construct a new form of the concept organisation in which relevant concepts are distributed around the target concept according to the relative distance in the semantic network. This organisation of concepts acquired by the reaction time technique can reveal more fundamental and deeper relations between concepts than the forms acquired by other techniques, such as concept mapping. Although different forms of the concept organisation regarding chemical equilibrium have been identified (Gussarsky & Gorodetsky, 1988, 1990; Mai, et al, 2021; Wilson, 1994, 1996), there have been so few reports using reaction time technique on the learning of chemical equilibrium that chemistry education researchers had no idea what this organisation of concepts was like and what the targeted suggestions for teaching practice were. To deeply understand how the students organise the relevant concepts in long-term memory after learning and to optimize the teaching design and practice, chemistry education researchers can explore and analyse this new group level organisation of concepts held by students.

Research Questions

This research utilized the reaction time technique to explore the group level organisations of concepts regarding chemical equilibrium in upper-secondary school students studying chemistry at different levels of academic achievement. The research questions solved in this research were as follows:

(1) How long is the reaction time of the concepts related to chemical equilibrium?
(2) How are the organisations of concepts regarding chemical equilibrium?

Research Methodology

General Background

This research conducted a cognitive psychology-oriented test to explore the organisation of concepts regarding chemical equilibrium at group level, involving 247 upper-secondary school twelfth-grade students as participants in Guangzhou, China during the 2019-2020 academic year. The test utilized the reaction time technique and category judgment task to acquire the behavioural data from students with different levels of academic achievement in chemistry. The reaction time data concerning the judgement of relation between concepts were utilized to form and visualize the organisation of concepts.

Participants

Research studies on psychology using reaction time technique usually involve only a few dozen or fewer participants (Jiang, 2012). To more accurately represent the new organisation of concepts at the group level from the reaction time data, this research enlarged the sample size to acquire a large number of valid dates, taking two or three classes of students from a school as a group.

In consideration of the practical feasibility, more than two hundred Chinese twelfth-grade students (16-17 years old) studying chemistry at different levels of academic achievement were invited and participated in the test. Participants came from two upper-secondary schools in Guangzhou, China, including 148 students in three

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classes at School A and 99 students in two classes at School B. The invitation was conducted with the help of school administrators. The students agreed to accomplish the test after understanding the purpose of this research.

Students' level of academic achievement in chemistry was determined according to the result of the chemistry academic achievement test conducted by the regional education administration department. The scope of the test included the whole content of the Chinese upper-secondary school chemistry curriculum. Students at School A had an outstanding performance in the test. Their average test score was in the top 6% of all 120 upper-secondary schools and significantly higher than the average test score of all schools. Students at School B studied chemistry at an average level, whose average test score was close to the average test score of all schools, ranking 44th among all schools. Before participating in this research, the students had studied the topic of chemical equilibrium in a chemistry elective module (Song, 2007b) and known the meaning of the concepts utilized in the task.

To eliminate the data bias that occurred in the task, 49 students were excluded by the criteria (more details were shown in the Data Analysis session). The valid sample comprised 198 students (valid rate: 80.2%, average age = 16.37 ± 0.48 years, 87 males and 111 females), including 124 students from School A (Group A), and 74 students from School B (Group B).

Instrument and Procedures

In the authors' previous research (Mai, et al, 2021), 24 concepts related to chemical equilibrium were selected from Chinese upper-secondary school chemistry curriculum materials (MOE, 2003, 2018; National Education Examinations Authority, 2018; Song, 2007a, 2007b; Wang, 2007; Wang, et al., 2007; Wang, 2014a, 2014b) and rated by a large number of chemistry research and teaching practice experts. According to the relations between concepts in chemistry and advice of some experts, these concepts were divided into six dimensions (shown in Table 1), which represented different parts of learning content regarding chemical equilibrium. It is worth noticing that the concept 'feature of chemical equilibrium' is a commonly used concept in Chinese upper-secondary school chemistry teaching. Chinese chemistry teachers utilize this concept to refer to five features of chemical equilibrium, such as 'reversible', 'dynamic', and other features so that students can quickly understand diverse aspects of chemical equilibrium. Using this concept familiar to students in this research was appropriate and necessary. Moreover, in the research material development, some students similar to the participants were able to distinguish the meaning of the concepts in a small group interview. These concepts were suitable for exploring students' organisation of concepts regarding chemical equilibrium in this research.

Table 1
Twenty-four Concepts Related to Chemical Equilibrium and Its Dimensions

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

The category judgment task comprised a training task on the subject of the galvanic cell including 48 training trials, and a testing task regarding chemical equilibrium including 48 formal trials. Twenty-four concepts related to the galvanic cell and 24 irrelevant concepts were utilized as test items in training trials. On the other hand, 24 concepts related to chemical equilibrium and 24 irrelevant concepts were utilized as test items in formal trials. Irrelevant concepts were of other themes regarding atomic structure, common compound, and experimental operation. Concepts regarding the galvanic cell and irrelevant concepts were all selected and rated by some chemistry

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research and teaching practice experts. The purpose of using irrelevant concepts was to focus participants' attention on their tasks. Each item was utilized in a trial without repeat.

Photographs involving those items were utilized as test materials. The background of the photograph is black, but the Chinese name of the target concept presented on the left and that of the item presented on the right are white (examples are shown in Figure 1). Item 'dynamic equilibrium' in Figure 1(a) is utilized as a relevant item when item 'nonpolar bond' in Figure 1(b) is utilized as an irrelevant item. The Chinese font size is 54 points to make participants watch the items.

Figure 1

Examples of the Photographs Presented in the Task

(a) Chemical equilibrium - Dynamic equilibrium (b) Chemical equilibrium - Nonpolar bond

The category judgment task was conducted on a personal computer by using E-Prime 2.0. Basing on the setting procedure, E-Prime selected a photograph of an item as a stimulus in random order and presented it on the computer screen in each trial.

Participants accomplished the category judgment task individually in the computer room of the upper-secondary school. The task included three stages. First, participants were presented with instructional slides to understand the aim and process of the task. Next, in training trials, participants were required to judge whether each item presented on the computer screen was related to the target concept 'galvanic cell', and to press on different buttons as quickly and correctly as possible. If the participant judged the presented item was related to the target concept, then pressed on the 'F' button, or else pressed on the 'J' button. Presented items were divided into two categories by participant's judgment. After experiencing the training trials and familiarizing the operation, participants judged whether the presented items were related to the target concept 'chemical equilibrium' in formal trials. The whole task cost approximately 15 minutes. E-Prime measured and recorded automatically participant's response and reaction time of each trial. The procedures were conducted following the Ethical Principles for Psychologists and Code of Conduct of the American Psychological Association.

Data Analysis

Three methods of data cleaning were conducted to improve the data quality. First of all, for each participant, the reaction time of less than 300 ms was removed because the data did not result from a genuine word recognition process (Jiang, 2012). Second, based on the Pauta criterion, the reaction time more than or less than 2 *SD* from the mean of the same participant was treated as outliers and eliminated (Jiang, 2012). Third, according to the advice of Jiang (2012), Babai and Amsterdamer (2008), the participants were excluded who had a rate of accuracy of responses less than 80%, and who had less than two correct responses in trials belonging to a concept dimension. As a result, the data from 198 students were thus accepted.

Because the analysis of students' organisation of concepts regarding chemical equilibrium was the aim of

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this research, the data of correct responses in formal trials were analysed by using SPSS 23.0. First, the mean reaction time of each item and that of each concept dimension related to chemical equilibrium were calculated. Then, Two-factor repeated measure ANOVA was performed on students' reaction time of correct responses, exploring the interaction effect between the type of school and the concept dimensions. Finally, the Bonferroni method was utilized in multiple comparisons of mean reaction time of different concept dimensions.

According to spreading activation theory and the assumption held by this research, the length of reaction time for each item was considered as an indicator to represent the relative distance between the corresponding relevant concept and the concept 'chemical equilibrium'. The reaction time of all items was combined to form the students' visual organisation of concepts in the radar chart.

Research Results

The Accuracy of Category Judgment Responses

Although the rates of correct classification for two groups of students were high (M_A = 91.87%, SD_A = 4.08; M_B = 89.64%, SD_B = 4.04), a significant difference was found in the rate between Groups A and B [t = 3.736, $p < .001$, Cohen's d = 0.549 (medium effect)]. Group A had a significantly better performance than Group B in judging the items related to chemical equilibrium.

The Reaction Time of Category Judgment Responses

Table 2 shows the mean reaction time of six concept dimensions. They were listed in descending order as below: Representation of state > condition > feature of equilibrium > shift of state > reaction rate > reversible reaction.

Table 2
Reaction Time (ms) of Six Concept Dimensions

Dimension	*M*	*SE*	Multiple comparisons
1. Representation of state	1167.05	398.66	1 > 2; 1, 2, 3, 6 > 4; 1, 3, 6 > 5
2. Shift of state	1013.75	323.68	
3. Feature of equilibrium	1073.32	390.41	
4. Reversible reaction	929.87	305.72	
5. Reaction rate	960.34	345.14	
6. Condition	1080.56	363.46	

There was no interaction effect between the type of school and the concept dimensions [F = 0.991, p = .419]. Only a significantly main effect of the concept dimensions was found [F = 17.944, $p < .001$, η_p^2 = 0.084 (medium effect)]. The results of multiple comparisons are shown in Table 2. First, the mean reaction time of the dimension 'reversible reaction' was significantly shorter than those of the other four dimensions ($p < .05$). Moreover, the mean reaction time of the dimension 'representation of state', 'feature of equilibrium', and 'condition' was significantly longer than that of the dimension 'reaction rate' ($p < .01$), respectively. Furthermore, a significantly longer mean reaction time was found for the dimension 'representation of state' than for the dimension 'shift of state' ($p < .001$).

The mean reaction time of the items in Groups A and B is listed in Table 3. Basing on the results, the item 'reaction quotient' had the longest mean reaction time in Groups A and B (1354.58 ms and 1276.14 ms respectively). Oppositely, the mean reaction time of the item 'reverse reaction' in Group A (828.33 ms) and that of the item 'rate of the forward reaction' in Group B (878.19 ms) was the shortest, respectively.

On the other hand, the mean reaction time of quite a few items in Groups A and B was not consistent. For example, except for the items 'Le Chatelier's Principle' and 'reversible process', the mean reaction time of other items belonging to the dimensions 'representation of state', 'shift of state' and 'feature of equilibrium' in Group A, was longer than those in Group B.

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Table 3
Reaction Time (ms) of the Items in Groups A and B

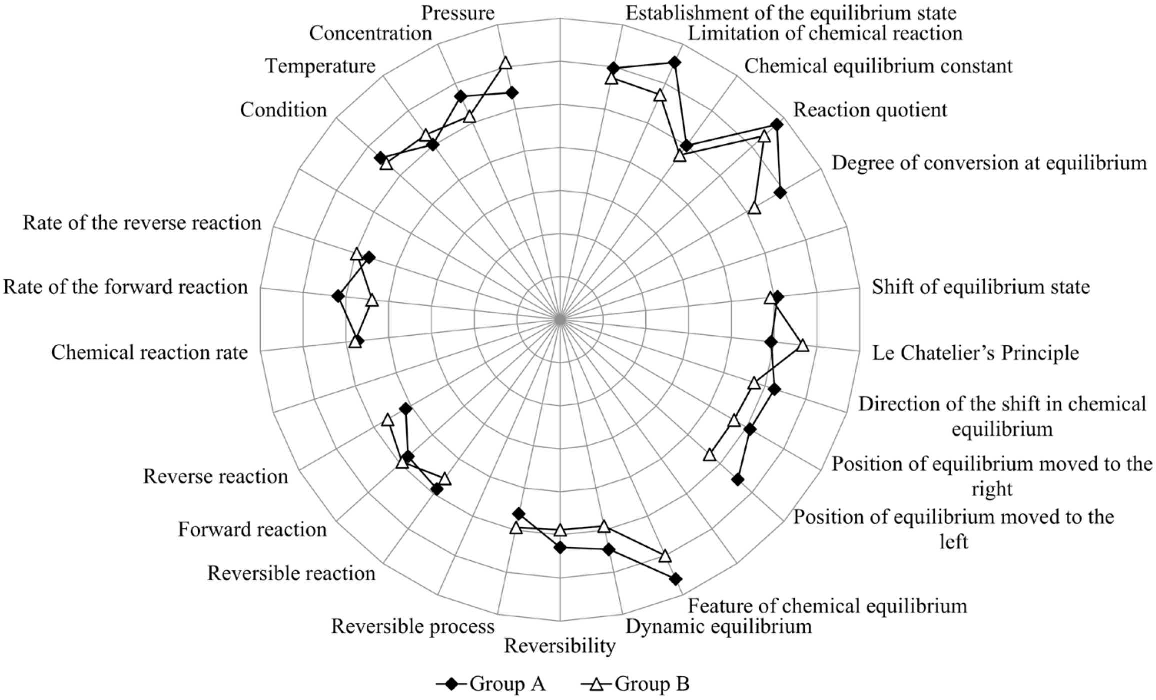
Dimension	Item	Group A		Group B	
		M	*SD*	*M*	*SD*
Representation of state	Establishment of the equilibrium state	1194.05	675.19	1147.97	601.53
	Limitation of chemical reaction	1307.37	672.74	1143.00	453.80
	Chemical equilibrium constant	999.41	496.11	944.43	492.47
	Reaction quotient	1354.58	716.73	1276.14	542.23
	Degree of conversion at equilibrium	1180.68	826.07	1041.57	458.15
Shift of state	Shift of equilibrium state	1015.18	492.17	982.41	534.19
	Le Chatelier's Principle	985.83	384.66	1132.19	339.41
	Direction of the shift in chemical equilibrium	1047.44	582.20	947.06	461.93
	Position of equilibrium moved to the right	1018.84	792.58	932.33	493.16
	Position of equilibrium moved to the left	1110.63	726.99	934.50	368.56
Feature of equilibrium	Feature of chemical equilibrium	1318.76	922.73	1199.46	605.62
	Dynamic equilibrium	1090.69	614.21	980.46	450.33
	Reversibility	1057.84	558.78	976.11	427.33
	Reversible process	921.54	484.94	986.85	526.27
Reversible reaction	Reversible reaction	972.92	655.41	912.29	491.95
	Forward reaction	950.26	496.21	987.37	545.87
	Reverse reaction	828.33	311.94	925.31	405.33
Reaction rate	Chemical reaction rate	944.71	447.93	957.26	539.36
	Rate of the forward reaction	1037.29	680.60	878.19	362.53
	Rate of the reverse reaction	933.61	399.12	993.07	441.72
Condition	Condition	1121.70	622.72	1085.93	526.38
	Temperature	1004.39	456.17	1060.92	436.02
	Concentration	1134.49	875.81	1034.95	592.17
	Pressure	1076.89	552.40	1221.58	442.68

The Organisation of Concepts

In Figure 2, the centre of the circle in the radar chart is regarded as the target concept 'chemical equilibrium'. The distance between two adjacent circles represents the reaction time of 200 ms and the excircle thus represents the reaction time of 1400 ms. The dots representing the items of six dimensions are distributed over six different parts of the circle. The positions of those dots are determined by the mean reaction time of their corresponding items. Therefore, Figure 2 represents the organisations of concepts from Groups A and B in the semantic network.

Figure 2

Radar Chart Representing the Organisations of Concepts Regarding Chemical Equilibrium



Note: The scale indicates 200 ms.

As shown in Figure 2, comparing to the dots of the items belonging to other dimensions, the dots of the items belonging to the dimensions 'reaction rate' and 'reversible reaction' are closer to the centre of the circle. Next, although the concept 'reaction quotient' is essential to identify the state of chemical equilibrium, its corresponding dot is far from the centre of the circle.

Moreover, by comparison with Group A, the dots of the items belonging to the dimensions 'representation of state', 'shift of state', and 'feature of equilibrium' in Group B are closer to the centre of the circle. For most dots of the items, the distance from the dot to the centre of the circle is different between the two groups. In brief, the organisations of concepts from two groups of students were inconsistent. However, because the main effect of the type of school was not found in this research, the difference in the organisations of concepts between the two groups of students was not significant.

Discussion

This research employed the category judgment task to acquire the reaction time from upper-secondary school students, revealing the new organisation of concepts regarding chemical equilibrium at the group level. Reaction time was utilized as a relative distance to indicate how close the relevant concepts were to the concept 'chemical equilibrium' in the semantic network, and how the organisation of concepts was. Four parts of the results were discussed as follows.

The Accuracy of Responses

First, the accuracy of responses from students was discussed. The concepts related to chemical equilibrium were rated by chemistry research and teaching practice experts, who could judge the knowledge space of chemical equilibrium (Mai, et al, 2021). In this research, the students studying chemistry at an outstanding level of academic achievement might more deeply understand the relations between the relevant concepts and the concept 'chemical equilibrium' and have a wider knowledge space than other students with a lower level of academic achievement in chemistry. As a result, if students held more knowledge space with the experts, they could judge so much more correct concepts into the relevant category that they accomplished a higher accuracy of responses.

Similarly, in the limit-time free word association test, Gussarsky and Gorodetsky (1990) also found that the number of concepts written by Israeli upper-secondary school students with the basic level of academic achievement in chemistry was smaller than that written by the students studying chemistry at a higher level of academic achievement. These results of the accurate responses were consistent with the researchers' expectations.

The Reaction Time of the Dimensions

The second discussion was on the subject of the dimensions with short reaction time. For all students participating in this research, the mean reaction time of the dimension 'reversible reaction' was the shortest in all dimensions, and that of the dimension 'reaction rate' was the second. It suggested that the concepts of the dimensions 'reversible reaction' and 'reaction rate' were significantly closer to the concept 'chemical equilibrium' than other concepts in the semantic network. It was also proposed that the distances from the concepts of different dimensions to the target concept were different.

Because the relevant concepts stored in the semantic network were the learning outcome, the above findings could be explained from the perspective of chemistry teaching practice. Although the chemical reaction rate is the essential content of chemical kinetics and chemical equilibrium is belonging to the core content of chemical thermodynamic, they are in close relation in chemistry. In fact, at the beginning of the chapter on chemical equilibrium, Chinese upper-secondary school chemistry textbooks introduce the concept 'chemical equilibrium' by discussing the change combining the rate of the forward reaction and that of the reverse reaction (Song, 2007a, 2007b; Wang, 2014a, 2014b). Moreover, chemistry teacher requires students to analyse diverse kinds of 'chemical reaction rate – reaction process' graph, discussing how chemical equilibrium establishes and shifts when the rate of reversible reaction changes in various reaction situations (Huang, et al., 2018; Liu, et al., 2017). It is easy for students to establish a high strength of the links among reversible reaction, the rate of a reversible reaction, and chemical equilibrium. Therefore, comparing to the concepts of other dimensions, the concepts of the dimensions 'reversible reaction' and 'reaction rate' can have higher frequencies of usage, so that they can appear more closely to the concept 'chemical equilibrium' in the organisation of concepts. As a result, when students saw those concepts as stimuli respectively, they could give a faster semantic activation and response. It made the reaction time of those corresponding items shorter.

Previous research studies have shown that students easily confused and conflated the concepts of chemical thermodynamics with those of chemical kinetics in the learning of chemical equilibrium (Bain & Towns, 2016; Van Driel, 2002). The finding in this research can provide evidence of structural knowledge to reveal the latent and discrete distributive relations involving these misapprehended concepts. The result helps researchers study the semantic understanding of these concepts in the future.

The Reaction Time of the Relevant Concepts

The third discussion focused on some items with long reaction time. The concepts 'reaction quotient' and 'feature of chemical equilibrium' are related to chemical equilibrium. In the teaching practice of chemical equilibrium, the chemistry teacher guides the students to compare the value of the reaction quotient to the value of the chemical equilibrium constant, in order to judge the shift direction of chemical equilibrium, and to interpret and exemplify the features of chemical equilibrium (Huang, et al., 2018; Song & Wang, 2016). In the research material development, some students in a small group interview could state the meaning of those concepts and agree to the significance of those concepts in the learning of chemical equilibrium. The mean reaction time of the items corresponding to those concepts was expected to be shorter than those of other items, but the result was the opposite of the authors' hypothesis. It revealed that those concepts might have long distances to the concept 'chemical equilibrium' in the semantic network, respectively.

The calculations involving reaction quotient and other quantitative processes regarding chemical equilibrium bring students the learning difficulties and varieties of misconceptions (Huddle & Pillay, 1996; Kousathana

& Tsaparlis, 2002; Ollino, et al., 2018). The authors assumed that students might focus on the process of problem-solving but not put more attention to the names of those concepts. Compared to other concepts, it thus made lower frequencies of those two concepts usage in student's learning experience. A longer reaction time occurred when students saw the stimuli regarding those two concepts. In addition, more evidence is needed for researchers to deeply explore this finding in the future.

The Organisation of Concepts

The fourth discussion was on the subject of the organisation of concepts for students. Comparing to different forms of the concept organisation (Gussarsky & Gorodetsky, 1988, 1990; Mai, et al, 2021; Wilson, 1994, 1996), the new form identified in this research did not provide the proposition networks or the categories of concepts but afforded the whole picture of all relevant concepts distribution according to the relative distance of each relevant concept in the latent semantic network.

Table 3 and Figure 2 depict and visualise the inconsistent and diverse organisations of concepts for students with different levels of academic achievement in chemistry. The authors assumed that two groups of students not only differed in the reaction time of the relevant concepts but also differed in the semantic activation and the degree of relatedness towards the relevant concepts, even in the frequencies of concept usage in formal learning.

Although students might differ in many aspects of the cognitive process regarding chemical equilibrium, students did not significantly differ in the organisation of concepts at the group level. In other words, students with different levels of academic achievement in chemistry constructed an organisation of concepts having no significant difference in long-term memory, respectively. It was probably because students perceived and understood the basic relations between concepts in chemistry teaching practice so that they could construct a similar organisation of concepts.

The organisation of concepts plays an essential role in concept understanding and problem-solving (Foster, 2009; Jonassen, et al., 1993; Solso, et al., 2014). The identified organisation of concepts provides the information about which relevant concept has a longer relative distance to the target concept and reminds chemistry teachers to pay attention to the teaching process and the interpretation of that concept. For example, chemistry teachers in both two groups can reflect on the teaching of the concepts 'reaction quotient' and 'feature of chemical equilibrium', while chemistry teachers in Group B noticing to explain the concept 'limitation of chemical reaction' in more depth.

Furthermore, the reaction time technique utilized in this research only produced the distances between the relevant concepts and the target concept. It did not produce the relative distances and the direct connection among the relevant concepts. The organisations of concepts representing in Figure 2 are incomplete and expected to be more complex. Therefore, the whole organisation of concepts will be acquired with the aid of additional techniques and tasks in the future.

Conclusions and Implications

Basing on spreading activation theory, this research explored the organisation of concepts regarding chemical equilibrium in upper-secondary school students by using the reaction time technique. The new and essential picture of the organisation of concepts was represented and analysed. The results showed that a significant difference between the reaction time of concept dimensions was found. Next, students studying chemistry at different levels of academic achievement did not have a significant difference in the organisations of concepts in the semantic network. The organisation of concepts combined by reaction time helps the chemistry education researchers to understand the form of the concept organisation in the long-term memory in-depth and to reflect the inadequacies of teaching practice.

Based on the overall results of this research, three implications are listed below. The first implication as a targeted suggestion for teaching practice is to deepen students' understanding of the relations between the relevant concepts and the concept 'chemical equilibrium'. Chemistry teachers can give more detailed descriptions of the relevant concepts to students and explain the key information of the concepts more deeply. Chemistry teachers can also conduct the learning tasks in which students apply the relevant concepts to interpret the progress and

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feature of chemical equilibrium and summarize the relations between concepts. The learning tasks are beneficial for students to increase the frequencies of concept usage and to restructure the organisation of concepts.

Next, the second implication regarding the research approach is to use the reaction time technique to conduct research studies on the organisation of science concepts. As shown in this research, the reaction time technique can be considered as an effective approach to acquiring students' judgment information to reflect the distance information of the concepts in the semantic network. Science education researchers can utilize this technique to explore the organisation of other science concepts and expand the knowledge of concept organisation.

Finally, the third implication based on the limitation of this research is to involve other appropriate tasks and techniques to acquire diverse evidence. This research only explored the organisation of concepts for students but not identified the relationship between the organisation of concepts and problem-solving ability of chemical equilibrium. In the future, by combining different kinds of task design in reaction time research and the paper-pen tests, the reaction time technique can be utilized as a supportive approach to depict how the organisation of concepts affects the performance of problem-solving. The findings will be helpful for researchers to gain a better understanding of the situation and function of the organisation of concepts.

Declaration of Interest

Authors declare no competing interest.

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